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**ENGINEERING STUDY OF STRUCTURAL GEOLOGIC FEATURES
OF THE HERRIN (NO. 6) COAL AND ASSOCIATED ROCK IN ILLINOIS**

Volume 2—Detailed report

Prepared for

**UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES**

by Hans-Friedrich Krausse, Heinz H. Damberger, W. John Nelson, and others

ILLINOIS STATE GEOLOGICAL SURVEY, Urbana, Illinois

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16. Abstract (Limit: 200 words) Roof failures in underground coal mines are related to the lithology and geologic structure of the roof. There are two distinct suites of roof rock above the Herrin (No. 6) Coal in Illinois, and each has distinctive patterns of structure and roof failure. In black shale-limestone roof areas, roof instability is correlated with thinning of limestone beds and presence of faults and clay dikes. In gray shale roof regions, the prime roof hazards are posed by rolls, shear bodies, and presence of coal or carbonaceous partings in the roof. Most structural features examined are believed to have formed during early stages of sediment diagenesis and compaction. Structural trends and lithologic patterns are strongly inter- dependent for this reason. In many cases geologic patterns are so com- plex and locally variable that prediction of roof stability far in advance of mining is difficult. The need for greater flexibility in roof control planning is apparent.				
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FOREWORD

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The detailed mapping in underground mines was performed mainly by Heinz H. Damberger, Hans-Friedrich Krausse, Christopher T. Ledvina, and W. John Nelson; the regional computer mapping was carried out by Colin G. Treworgy; the studies in surface mines and the development and application of close-range photogrammetry methods were completed by Vincent D. Brandow, H.-F. Krausse, W. John Nelson, and Colin G. Treworgy; Christopher T. Ledvina was in charge of core drilling in underground mines; the laboratory testing of the drill cores was carried out by Caner Zanback and Lester S. Fruth under the supervision of Alberto S. Nieto, Department of Geology, University of Illinois, Urbana; data and information on rock mechanics and roof failure trends were evaluated by Stephen R. Hunt; W. Arthur White was in charge of the clay mineralogy studies. The entire program was guided and directed by H. H. Damberger and H.-F. Krausse, and the final report was written and coordinated by H.-F. Krausse, H. H. Damberger, and W. J. Nelson.

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INTRODUCTION

The relationship of roof control to the local and areal geologic make-up of roof strata in coal seams has been identified as one of the least understood subjects of ground control (Van Besien, 1973). Therefore, a number of contracts have been let by the U.S. Bureau of Mines (1) to catalog data on roof conditions in mines as they relate to geologic features, (2) to understand the causal relationship between the geologic structure and prevailing roof conditions, stable or hazardous, and (3) to improve methods of roof control, or at least to provide warning in advance based on such knowledge.

The Illinois Basin contains vast coal resources, mostly within the boundaries of the state of Illinois. The Illinois State Geological Survey (ISGS) lists total coal resources of 161.6 billion tons for Illinois (Smith and Stall, 1975), 68.4 billion tons of which are in the Herrin (No. 6) Coal Member. Sixty billion tons, or 88 percent, of identified resources in the Herrin (No. 6) Coal are minable only by underground methods. The Herrin (No. 6) Coal seam has been and is being mined in western, west-central, southern, and northern Illinois and in Vermilion and Douglas Counties of eastern Illinois. In 1973, 75 percent of the coal produced in Illinois came from this seam. The Herrin (No. 6) Coal Member was therefore singled out for a special study of the influence of structural geologic features on roof conditions in underground mines in the Illinois Basin Coal Field.

Statement of goals

This report summarizes the status of our knowledge on the influence of the geologic and structural fabric of roof strata on roof stability in underground mines in the Herrin (No. 6) Coal. The report is based both on past investigations and on information collected during recent visits to active mines. More information needs to be collected and evaluated to develop methods for improving roof control and mine safety. The objectives of this study were as follows:

1. To identify and describe geologic conditions that influence roof stability
2. To relate roof performance to the geologic structure by detailed study within selected mines
3. To present information on areal distribution of comparable geologic conditions that influence roof stability
4. To compile from literature and files geotechnical data that pertain to roof stability
5. To collect samples from study areas by diamond drilling

6. To show how to recognize, both in mines and in diamond drill cores, the various geologic features that influence roof stability
7. To propose areas of future research on the subject

Previous work and data basis

The Illinois State Geological Survey for many years has had an active interest in the interrelationships between the geologic make-up of coal seam roof strata and roof conditions in underground mines, and mine operators have been advised on such relationships by Survey personnel as new mines were being planned or when active mines encountered roof problems. Numerous observations on the performance of the various roof strata and on the influence of structural geologic features are accumulated in the extensive collection of mine notes at the Survey, many of which have been discussed in ISGS publications. From this long experience it was realized that both lithology and thickness of the stratigraphic members above and below coals have significant influence on roof stability in underground mines. Roof conditions in mines having black shale-limestone roof are known to be substantially different from mines having gray shale-siltstone roof. A thick solid limestone in the immediate roof usually provides a stable roof, whereas roof control might become a problem where there is no thick limestone or where the roof is formed by a thin layered sandstone that has partings of plant debris. Furthermore, certain structural features and fabrics have been recognized in some lithologies and areas but not in others. Therefore, a systematic retrieval, sorting, and evaluation of data on the areal variability of the stratigraphic members of the Herrin (No. 6) Coal roof sequence in Survey files (logs of boreholes and shafts, and descriptions of outcrops) is required to delineate areas of comparable roof conditions. A system for gathering this type of data for computer processing was developed at the Survey (Swann et al., 1970; Johnson, 1972). Almost a year was spent gathering and organizing all reliable data on areas of minable Herrin (No. 6) Coal and placing them in a computer-processible file. During the course of this roof study, extensive use was made of the Survey data base, which includes many thousands of detailed core descriptions, drillers' logs, and electric logs of core holes described and evaluated by Survey personnel. Electric logs of oil and gas drill holes have recently been used in an intensive investigation of the Illinois coal fields (Hopkins, 1968; Allgaier and Hopkins, 1975). Survey files also contain many data on structural features such as faults, rolls, slips, and joints which were collected over many years during brief mine visits and include data on most coals and associated rocks in the state; however, comprehensive areal studies in a number of mines were needed to develop a better understanding of interrelations between structural features, lithology, and stability of the roof.

Selection of study areas and activity plan

Most of the mines are near the rim of the Illinois Basin Coal Field. During 1975, 58 coal mines were operating in Illinois, of which 17 were underground mines in the Herrin (No. 6) Coal. The underground mines were visited during the initial phase of this study. In selecting mines and study areas for detailed investigation, a number of criteria were applied and compared. Most important were amount and quality of coal reserves in the areas and the potential for studying suitable examples of structural geological features that were recognized as contributing significantly to roof failures. We selected mines or areas for which much information, in particular good core descriptions, were available from Survey files.

Twelve study areas in seven mines were selected. Study areas 1 to 3, which have a black shale-limestone type of roof, and areas 4 to 9, which have a gray shale-siltstone type of roof, were delineated on mine maps at scales of 1 inch to 100 feet (1:1,200) or 1 inch to 200 feet (1:2,400). Study area 10 is in a strip mine having black shale-limestone roof. Many other mines, including study areas 11 and 12, were visited, and particular structural features were investigated. Study activities over the two-year period of this project are summarized in table 1.

TABLE 1. Summary of work progress.

1974												1975												1976													
J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F
1 <u>Compilation of computer processible data file on roof strata</u>												2 <u>Analyses of lithologic data in data file</u>																									
3 <u>Survey of mines</u>																																					
4 <u>Phase I report</u>																																					
												5 <u>Geologic mapping in mines</u>																									
												6 <u>Compilation and analyses of data from in-mine mapping</u>																									
																								7 <u>Structural analysis in single mines</u>													
8 <u>Development of photogrammetric capability</u>																																					
												9 <u>Photogrammetric analysis of underground mine sites</u>																									
																								10 <u>Photogrammetric analysis of advancing highwall</u>													
																								11 <u>Diamond drilling in mines</u>													
																								12 <u>Final report</u>													

THE GEOLOGY OF THE ILLINOIS BASIN COAL FIELD

Characteristics of the coal-bearing strata

The Pennsylvanian System is the youngest large bedrock system in the Illinois Basin and forms the uppermost bedrock unit for over 65 percent of Illinois (Hopkins and Simon, 1975). It is overlain by glacial deposits of Pleistocene age, which locally attain a maximum thickness of more than 400 feet (120 m) but are commonly much thinner. The Pennsylvanian is underlain by Mississippian or older Paleozoic rocks, which crop out around the outer margins of the Illinois Basin.

The Pennsylvanian System (fig. 1), which contains all the commercial coals in Illinois, reaches a thickness of about 2,500 feet (760 m) in the central part of the Illinois Basin. Thicknesses of up to 3,500 feet (1,070 m) have been recorded locally in down-faulted blocks in southeastern Illinois and western Kentucky. About 85 individual coals have been recognized in the Pennsylvanian System of the Illinois Basin Coal Field. Of these, about 20 have been mined at least locally through the years. Most of the identified coal resources (about 92 percent) in the state occur in the middle part of the Pennsylvanian System, in the Carbondale Formation, which consists of about 350 feet (107 m) of strata. Four coal members in the Carbondale Formation account for nearly all of the 92 percent (fig. 1). These are, from youngest to oldest: the Danville (No. 7)—4 percent, the Herrin (No. 6)—42 percent, the Springfield-Harrisburg (No. 5)—31 percent, and the Colchester (No. 2)—13 percent. About 80 percent of the state's current coal production is from the Herrin (No. 6) Coal.

The Carbondale Formation has long been known as the formation that best exhibits cyclothems, which are sequences of strata arranged vertically in a particular order that is repeated (Udden, 1912, and Weller, 1930 and 1931). Each cyclothem consists ideally of ten distinctive units (fig. 2); however,

frequently the cyclothems are incomplete. Fifty-four cyclothems have been named, including several hundred individual lithologic units, most of which vary from less than an inch to as much as 30 feet (9 m) thick; an occasional coarse-grained clastic unit exceeds 100 feet (30 m). The average thickness is about 3 to 5 feet (0.9 to 1.5 m).

Sandstones, many of which are interbedded with siltstone and laterally grade into siltstone and shale, are the most variable in thickness. Thicknesses of 30 to 50 feet (9 to 15 m) are common, and abrupt changes in thickness occur where the sandstone occupies erosional channels. A few sandstones are as much as 120 feet (36 m) thick in some areas. Shales may in places exceed 100 feet (30 m) in thickness, but 20 to 40 feet (6 to 12 m) is more common. The shales are much more persistent than the sandstones, and their variations in thickness generally are more gradual than those of sandstones, except where they are truncated by sandstone channels. Claystones (underclays) are generally 2 to 5 feet (0.6 to 1.5 m) thick; locally, claystone-dominated sequences may be as much as 30 feet (9 m) thick. The black fissile shales, commonly

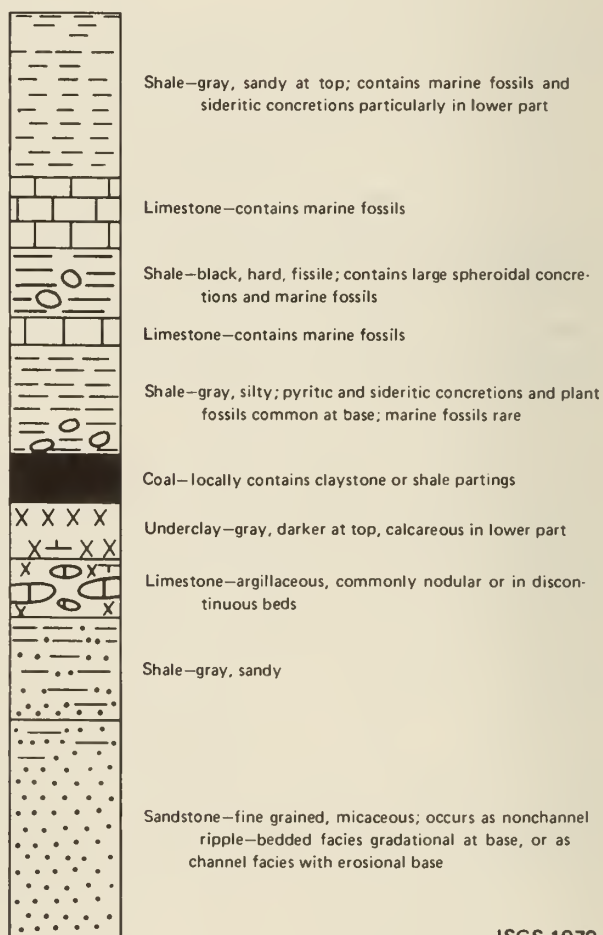
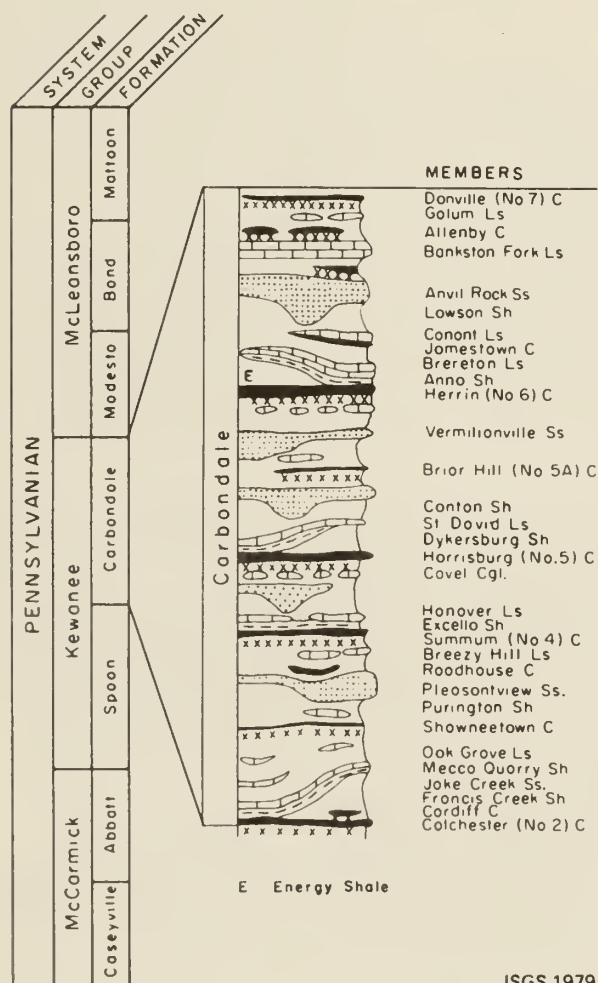


Figure 1. Stratigraphic section of the Carbondale Formation, Kewanee Group, showing the positions of the most important coals within the Pennsylvanian System in Illinois. (After W. H. Smith, 1975.)

Figure 2. Arrangement of lithologic units in a cyclothem. (After Willman and Payne, 1942.)

found directly above a coal seam, are usually 1 to 3 feet (0.3 to 0.9 m), and in places as much as 7 feet (2.1 m) thick. Most of them are marine deposits.

The limestones vary greatly in thickness. Some persistent limestone beds are less than a foot (<0.3 m) and others as much as 50 feet (15 m) thick have been observed in the upper part of the Pennsylvanian; however, thicknesses of 2 to 4 feet (0.6 to 1.2 m) are most common. Marine limestones predominate, but freshwater limestones are also known, particularly within and beneath underclays.

Most coals are 6 inches to 3 feet (15 to 90 cm) thick, but they range from scarcely more than a thin carbonaceous streak to a maximum thickness of 15 feet (4.5 m). A few coals, particularly the Herrin (No. 6) and the Springfield-Harrisburg (No. 5) Coals, average 3 to 7 feet (0.9 to 2.1 m) in thickness over large areas.

Overall, 90 to 95 percent of the sediments of the Pennsylvanian System in Illinois are siliceous clastics (sandstones, siltstones, and shales). About 50 to 60 percent are argillaceous rocks (47 percent relatively soft shales, 2 percent underclays, and 1 percent black fissile shales). About 5 percent of the sediments are calcareous rocks or limestones, some of which are dolomitic or ankeritic. One to 2 percent are coal. All other types, including siderite and chert, make up less than 2 percent of the total.

Structure of the Herrin (No. 6) Coal Member in the Illinois Basin

The present structural configuration of the Illinois Basin is the result of (1) a subsiding embayment open to the south during deposition of the Pennsylvanian sediments, similar to the present configuration of the Mississippi Embayment, and (2) a subsequent uplifting of the southern rim of the basin; probably at the same time additional downwarping of the basin interior and development or accentuation of most of the anticlines, monoclines, and faults occurred. The resulting basin, as defined by the extent of the Pennsylvanian sediments, lies in the southern two-thirds of Illinois, southwestern Indiana, and the northern part of western Kentucky. Regional dips are extremely gentle, in most places 10 to 30 feet per mile (2 to 6 m/km). Herrin (No. 6) Coal crops out around the periphery of the basin at elevations of around 400 to 800 feet (120 to 240 m) above sea level and dips gently to elevations of 750 to 850 feet (230 to 260 m) below sea level in the central part of the basin. Most of the anticlines and synclines are wide, gentle, and open, and have dips of 1° to 2° . Occasional dips of up to 15° are found on more prominent structures, such as the La Salle Anticlinal Belt (Clegg, 1970). Locally along some of the major faults, such as the Shawneetown Fault, much steeper dips have been observed.

The structural setting of the Illinois Basin through geologic history is more complex than is apparent. Numerous structural elements, including arches, basins, synclines, anticlines, monoclines, and faults have a significant influence on the continuity, thickness, and other properties of the coals. Positions and trends of some important structures are shown in figure 3.

Geology of the Herrin (No. 6) Coal Member and its roof strata

This section is provided for general background and as a framework for the much more detailed discussion of roof types that follows. This part

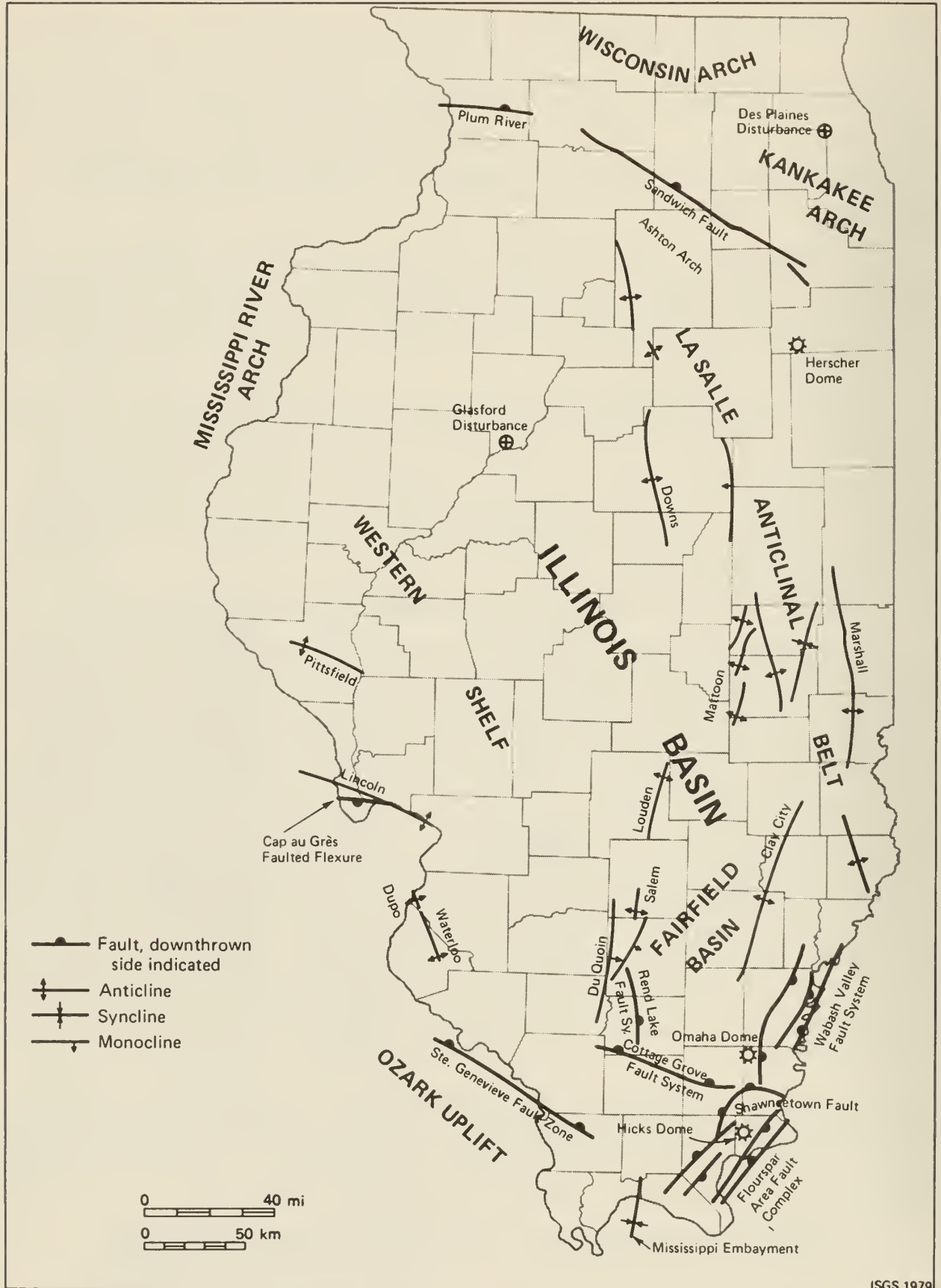


Figure 3. Geologic structures of Illinois.

is based primarily on Hopkins and Simon (1975); the section on roof types is based on field work completed during this study.

THE HERRIN (NO. 6) COAL MEMBER

The Herrin (No. 6) Coal Member of Illinois is called "No. 11 Coal" in western Kentucky and "Herrin Coal Member" in Indiana. The Herrin (No. 6) Coal is correlated with the Lexington Coal in Missouri and the Mystic Coal Member in Iowa and commonly consists of a normal bright-banded, high-volatile A, B, and C bituminous coal (ASTM Standard D388). The lower third of the seam contains a regionally rather persistent and prominent claystone parting up to three inches (7.5 cm) thick called the "blue band."

The Herrin (No. 6) Coal seam is underlain by a well-developed underclay. The average coal thickness ranges from six to seven feet (1.8 to 2.1 m). Locally it reaches 15 feet (4.5 m) in thickness, but it is thinner (5 feet and less) in extensive areas of central Illinois. The sulfur content of the coal is 3 to 4 percent, but locally reaches 5 to 6 percent. Where thick shale of the Energy Shale Member (20 feet; 7 m or more) overlies the coal seam, the sulfur content is as low as 0.5 percent (e.g., in the "Quality Circle" of southern Illinois, fig. 4). Syngenetic and diagenetic deformational features such as "rolls," shear planes (slips), locally isoclinal recumbent folds, "horsebacks," clastic dikes, dilatational fractures, cleats, and faults commonly have affected, deformed, and penetrated the coal seam.

The Herrin (No. 6) Coal is the most widespread minable coal in the Illinois Basin Coal Field. About 88 percent lies at depths amenable only to underground mining. Most of the identified coal resources in the Herrin (No. 6) Coal have an average coal thickness of at least 5 feet (1.5 m) and lie within a 60- to 70-mile-wide (100 to 115 m) belt along the southern, southwestern, and west-central part of the Illinois Basin (figs. 4 and 5). Although large quantities of coal have already been mined in this belt, especially in the "Quality Circle," large reserves of thick coal remain. Another area having identified resources of thick (>5 feet [>1.5 m]) Herrin (No. 6) Coal is in Jasper, Richland, and Wayne Counties, part of the Fairfield Basin. There the coal lies at a depth of about 1,200 feet (365 m), whereas the coal along the southern, southwestern, and west-central part of the Illinois Basin Coal Field lies at much shallower depths, generally at about 700 feet (210 m) or less. Future underground coal mining in Herrin (No. 6) Coal will probably concentrate in the deeper part of the basin.

In Illinois, the Herrin (No. 6) Coal seam is most commonly overlain directly by the Anna Shale Member, but in the vicinity of paleochannels, the Energy Shale overlies the coal seam underneath the Anna Shale. Where the Energy Shale and the Anna Shale are absent because of local anomalies, the Brereton Limestone Member (or, where that also is missing, the "Jamestown Coal interval" directly overlies the Herrin (No. 6) Coal. Throughout most of the state, the immediate 20 to 25 feet (6 to 7.5 m) of strata above the coal are the principal elements involved in roof stability or characteristics.

GEOLOGY OF THE ROOF STRATA OF THE HERRIN (NO. 6) COAL MEMBER

The sequence of strata in the first 40 to 50 feet (12 to 15 m) above the Herrin (No. 6) Coal is variable both vertically and laterally, as shown in figure 6. The most persistent named units in the roof strata are the Anna

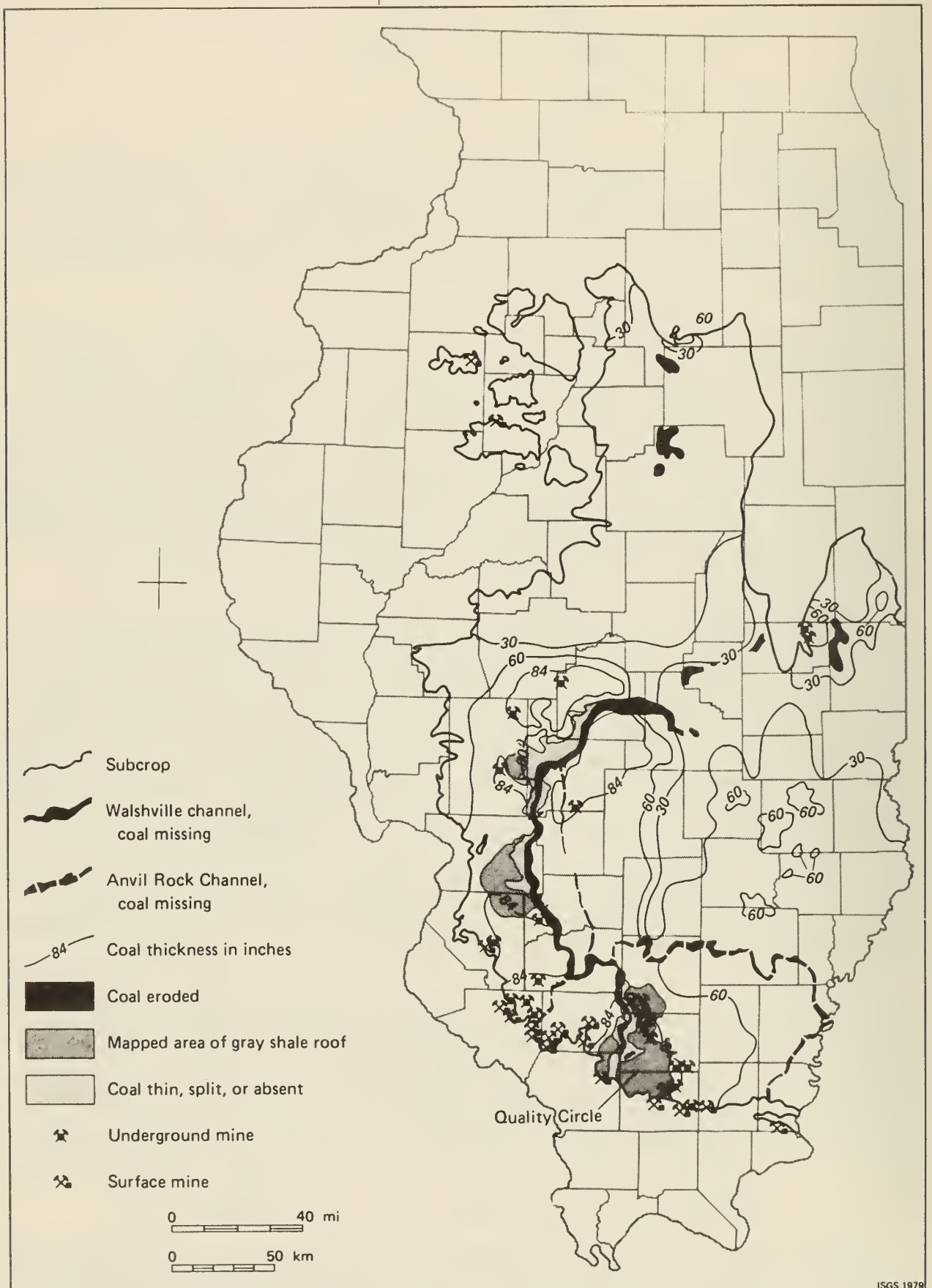


Figure 4. Distribution of the Herrin (No. 6) Coal in Illinois.

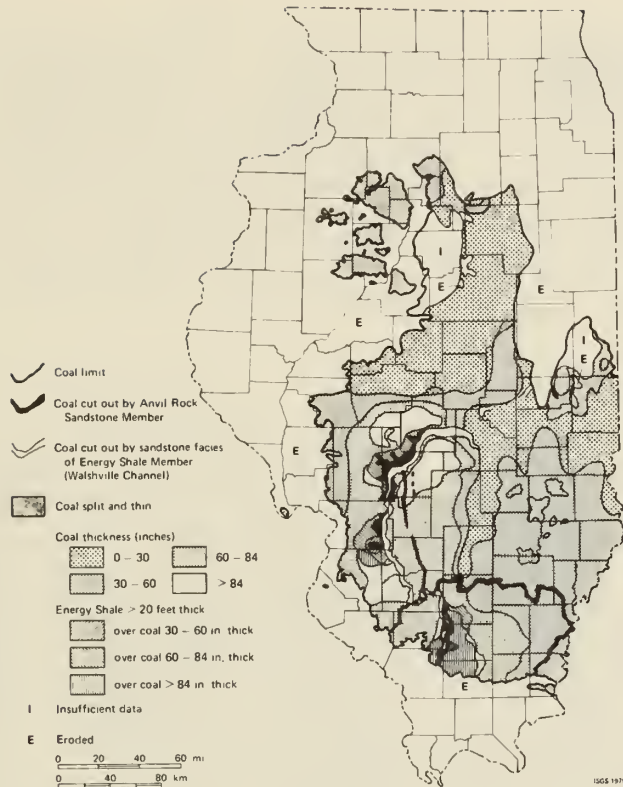


Figure 5. Generalized thickness of Herrin Coal.

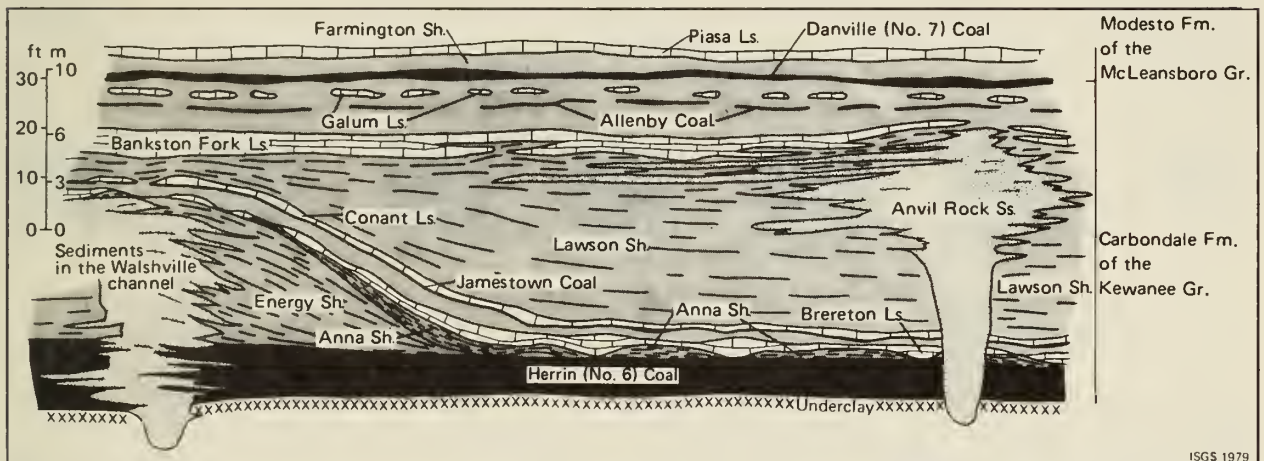


Figure 6. Schematic section of the interval between the Herrin (No. 6) Coal Member and the Piasa Limestone Member. (After G. J. Allgaier, June 1974.)

Shale, Brereton Limestone, Bankston Fork Limestone, Danville (No. 7) Coal, and Piasa Limestone Members. The Energy Shale, the Lawson Shale, and the Anvil Rock Sandstone Members vary the most in both thickness and extent.

The Energy Shale Member and sediments that fill the Walshville channel

The Energy Shale Member (Allgaier and Hopkins, 1975) directly overlies the Herrin (No. 6) Coal in several limited areas of the Illinois Basin (fig. 4).

It consists of gray shales, siltstones, and sandstones, and its thickness varies greatly (0 to 100 feet [0 to 30 m]). The Energy Shale is best known and has been studied primarily in the "Quality Circle" of southern Illinois (fig. 4), but is also known from other areas of the Illinois Basin. The "Quality Circle" area lies in Jackson, Williamson, Franklin, and Jefferson Counties, east of the Du Quoin Monocline and directly east of the Walshville channel at the southwestern rim of the Fairfield Basin. The "Quality Circle" is limited to the area where the Energy Shale Member is over 20 feet (6.1 m) thick and where the sulfur content of the coal is generally less than about 2 percent (Gluskoter and Hopkins, 1970).

The Walshville channel fill

Sediments that fill the Walshville channel system and those of the Energy Shale Member are genetically related. The Walshville channel, named by Johnson (1972), represents a paleochannel system that interrupts the continuity of the Herrin (No. 6) Coal and some floor as well as roof strata (fig. 6) and has been known for many years (Potter and Simon, 1961). Instead of coal, mainly sandstone and siltstone and, less frequently, silty shale and shale, are found in the channel. The Walshville channel is traceable for a distance of about 170 miles (274 km) and is as much as 2 miles (3 km) wide (fig. 4). Channel deposits average about 80 feet (24 m) in thickness, but locally exceed 100 feet (30 m).

Adjacent to the Walshville channel, the Herrin (No. 6) Coal commonly has been found to be split (Potter and Simon, 1961; Johnson, 1972). Shale or siltstone partings are interlayered with the coal. These splits are thought to be genetically connected and contemporaneous with the deposition of sediments in the Walshville channel. Energy Shale strata more than 20 feet (6 m) thick commonly become coarser upward into siltstone. The upper part of the Energy Shale in places grades vertically and laterally into sheet sandstone. All the lithologies are usually well bedded. Where the thickness of the Energy Shale exceeds 20 to 30 feet (6 to 9 m), the next younger members, Anna Shale and Brereton Limestone, tend to thin irregularly and may pinch out entirely (fig. 7).

The Anna Shale Member

In most of the Illinois Basin Coal Field, the Anna Shale immediately overlies the Herrin (No. 6) Coal, except where the Energy Shale is present. The Anna Shale is named for the town of Anna in eastern Kansas. Its thickness commonly varies from 0 to 4 feet (0 to 1.20 m) and seldom exceeds 5 feet. The Anna Shale consists of carbonaceous black shales having marine fossils and abundant small phosphatic nodules (see p. 64). The lower part is often fissile and well-jointed.

Although regionally persistent over most of the Interior Coal Province, especially within the Illinois Basin Coal Field, the Anna Shale Member is locally lenticular and pinches out. It is normally overlain by the Brereton Limestone Member, but where the Brereton Limestone is absent, the Jamestown Coal Member and its associated floor rocks, or where those units are missing the Lawson Shale or the Anvil Rock Sandstone Members overlie the Anna Shale.

The Brereton Limestone Member

The Brereton Limestone (Savage, 1927), which commonly overlies the Anna Shale, is recognized throughout most of the Illinois Basin. It is regionally

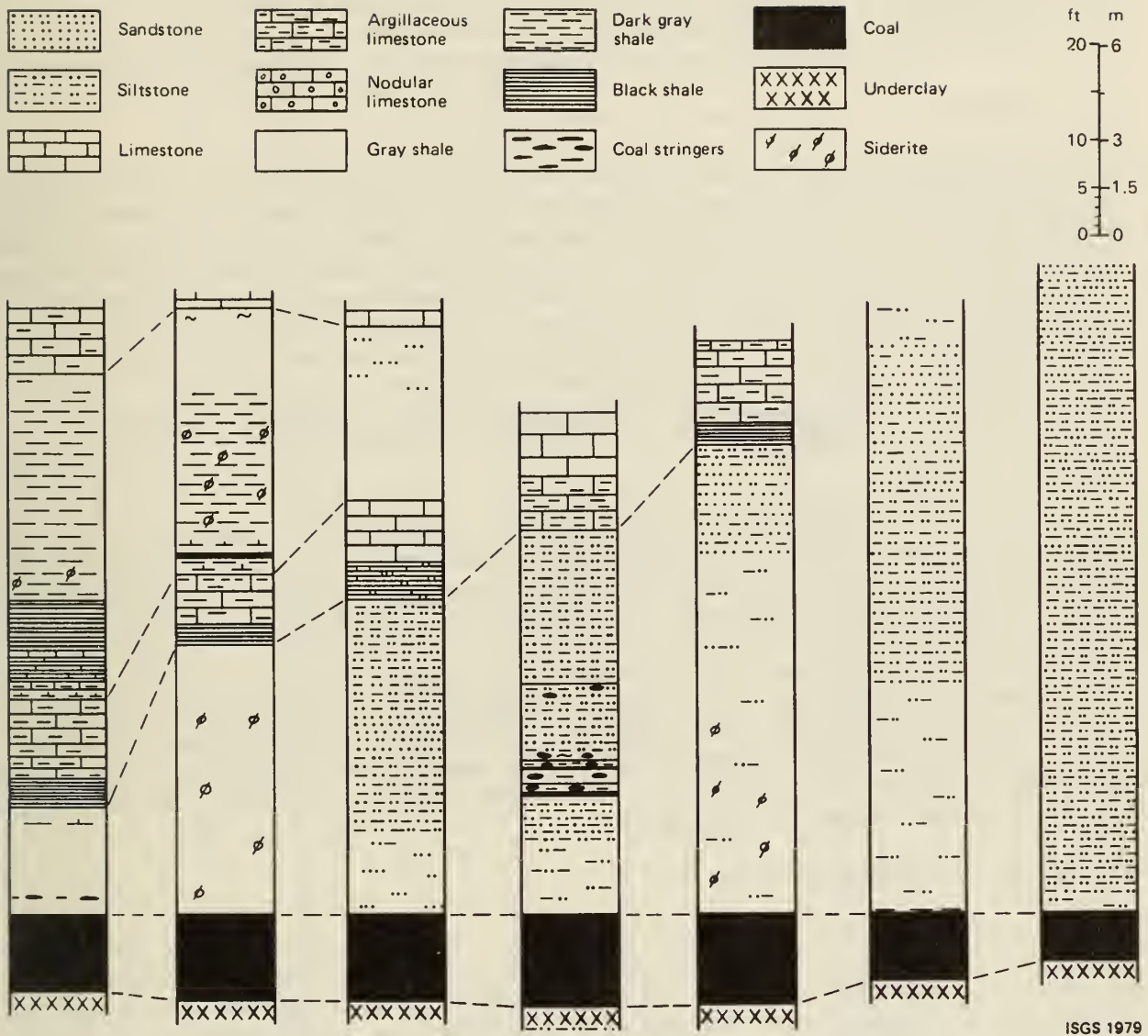


Figure 7. Examples of lithologic sections of the Energy Shale Member and overlying strata. Most sections are from the "Quality Circle" area in southern Illinois.

just as continuous as the Anna Shale, but may locally vary in thickness, be patchy and pinch out, or be absent. The Brereton Limestone is not only a prominent marker bed, but also a rock unit economically important to underground mining; where it is thicker than about two feet (0.6 m), it provides good anchorage for roof bolts.

The Brereton Limestone is named for the town of Brereton in Fulton County, Illinois, and previously was called Herrin Limestone. In Kentucky its name is Providence Limestone Member. It is correlated with the Myrick Station Member in Missouri. Although locally the thickness of the Brereton Limestone exceeds 10 feet (3.0 m), it averages four to five feet (1.2 to 1.5 m) thick. It contains open-marine fauna, comprising mostly brachiopods and fusulinids. The Brereton Limestone consists of gray impure limestone that may grade laterally and vertically into a calcareous shale. The Brereton Limestone is overlain

either by the Jamestown Coal and its associated rocks (as known from southeastern, southern, southwestern, and parts of west-central Illinois; southwestern Indiana; and western Kentucky) or the Lawson Shale or the sheet phase of the Anvil Rock Sandstone (west-central), northwestern, and northeastern Illinois).

The Jamestown Coal Member and its associated roof and floor rocks

The Jamestown Coal (Bell et al., 1931) is the next younger named member above the Brereton Limestone. It varies from a bright-banded, high-volatile bituminous coal to a shaly or bony coal or to a black, very carbonaceous shale having coaly streaks in some places. The Jamestown Coal is widespread but usually only up to a few inches thick in southern and southwestern Illinois, increasing in thickness to six feet (1.8 m) in eastern Illinois and further eastward into Indiana and Kentucky, where it is mined as Hymera Coal Member (VI) (Indiana) and No. 12 Coal (Kentucky) (Willman et al., 1975). The Jamestown Coal, however, has not been recognized in northern and western Illinois and in the northeastern part of the Illinois Basin, in Vermilion and Douglas Counties.

Associated unnamed floor rocks of the Jamestown Coal above the Brereton Limestone and roof rocks below the Conant Limestone (or, where this is absent, below the Lawson Shale) together with the Jamestown Coal have been informally called "Jamestown Coal interval" in this paper. The interval consists of various gray shales, a freshwater limestone, and thin coals. It varies in thickness from less than a foot to three feet (<0.3 m to 0.9 m) locally. The "Jamestown Coal interval" is underlain either by the Brereton Limestone or by Anna Shale where the Brereton Limestone is missing. In a few places, where both Brereton Limestone and Anna Shale are absent, the "Jamestown Coal interval" overlies the Herrin (No. 6) Coal. The "Jamestown Coal interval" is normally overlain by the Conant Limestone.

The Conant Limestone Member

Previously called "Jamestown Limestone," the Conant Limestone (Kosanke et al., 1960) is named for the town of Conant in Perry County, Illinois. It is variable in thickness (0 to 1.2 m). In most of southern and central Illinois, the Conant Limestone directly overlies the "Jamestown Coal interval." It has not been recognized in areas other than southern and central Illinois, but has been correlated with the Pokeberry Limestone Member, known from Schuyler County. This correlation is rather uncertain, however.

The Conant Limestone usually is less than one foot (0.3 m) thick, but in parts of Randolph and in St. Clair and Perry Counties it may reach four feet (1.2 m) in thickness locally. In this area it lies about four feet above the Jamestown Coal; a gray shale parting lies between them. The Conant Limestone consists of dark-gray limestone that may grade laterally into calcareous shale. It contains dolomitic concretions. Joints are abundant where the Conant Limestone consists of hard limestone or dolomite. In some areas it resembles the Brereton Limestone, comprising open-marine fauna, but is distinguished by white productid brachiopod shells and tabular foraminifera rather than brachiopods and fusulinids.

The Conant Limestone is usually overlain by the Lawson Shale. The thickness of the interval between the Herrin (No. 6) Coal and the Conant Limestone

may vary considerably (fig. 8) depending on the variations of thickness of the subjacent rock units (Energy Shale, Anna Shale, and Brereton Limestone).

The Lawson Shale Member, Anvil Rock Sandstone Member, and Copperas Creek Sandstone Member

The Lawson Shale, the Anvil Rock Sandstone, and the Copperas Creek Sandstone are younger than the Conant Limestone; where the Conant or older members are missing, they may overlie any of the older units down to the Herrin (No. 6) Coal or even below (fig. 6). The Lawson Shale Member (Kosanke et al., 1960) was formerly called the Sheffield Shale. It was not previously defined for southern Illinois, but has been correlated with formerly unnamed shale members underlying or interfingering as a facies with the Anvil Rock Sandstone. The Lawson Shale consists commonly of gray, poorly bedded shales. They generally

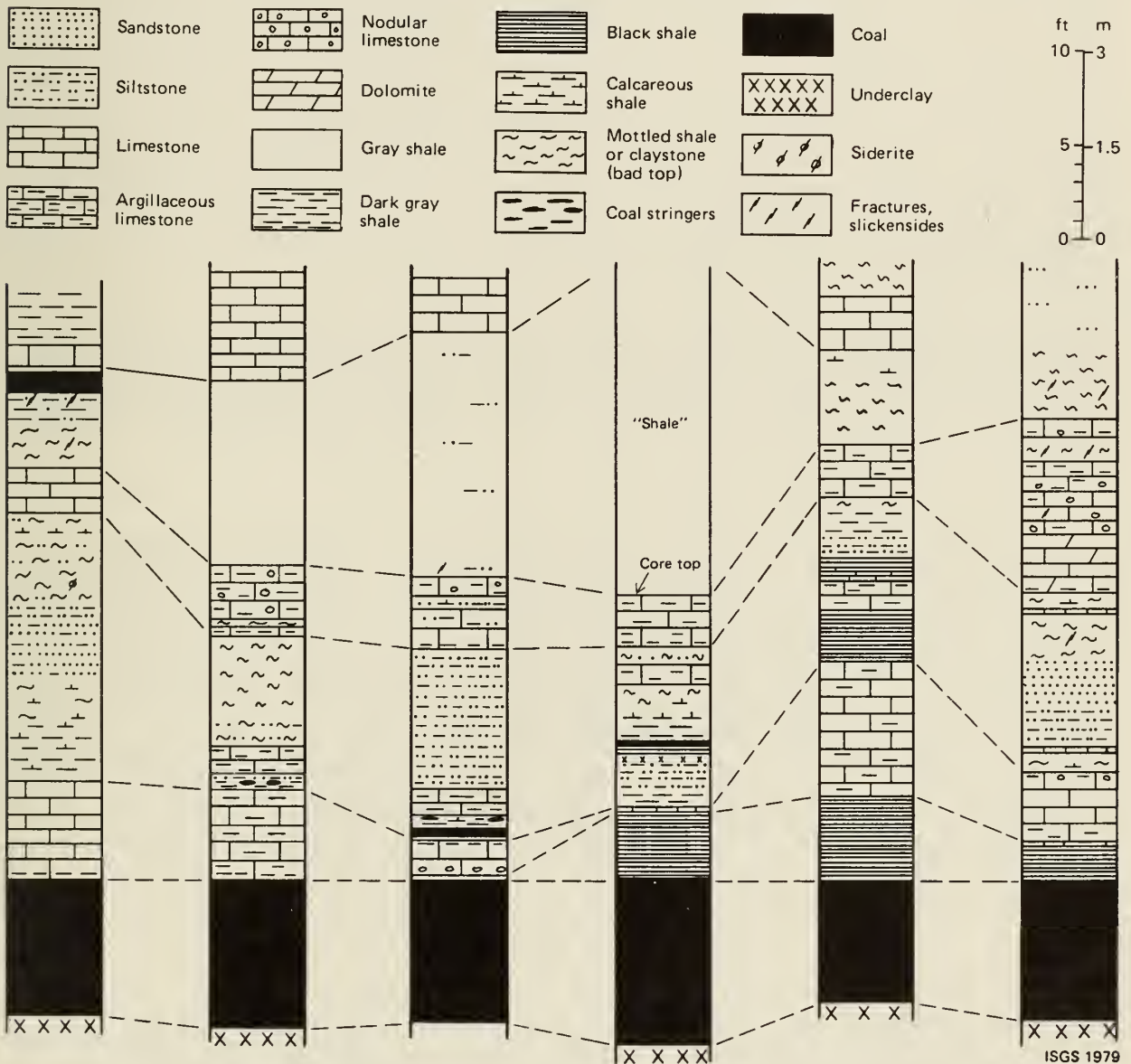


Figure 8. Examples of lithologic sections from the black shale and limestone roof type above the Herrin (No. 6) Coal Member, taken from core and outcrop descriptions at various locations in the Illinois Basin.

are considered to be nonmarine with occasional brackish influence. Fossils are scarce, but plant fossils are more frequently found than animal fossils. The shales laterally and vertically may grade into siltstones and sandstones. Facies changes may locally be rapid, and layers of silt or sandstones and, in a few places, even conglomerates are common. When directly overlying the Energy Shale, the Lawson Shale may be difficult to distinguish from the Energy Shale.

Not only lithology, but also thickness, of the Lawson Shale is highly variable, from about 6 to 50 feet (1.8 to 15.0 m). It is 2 to 25 feet (0.6 to 7.6 m) thick on the Western Shelf and as much as 50 feet (15 m) in areas where it is interbedded with siltstone close to channel systems of the Anvil Rock and the Copperas Creek Sandstones.

The Anvil Rock Sandstone Member occupies a part or all of the Bankston Fork/Conant interval and may interfinger with or overlie the Lawson Shale. The Anvil Rock Sandstone consists of fine-grained, impure, often argillaceous siltstone and sandstone forming a sheet deposit. Where it has been deposited as a channel filling, it may also consist of sandstone that is medium grained, seldom coarse grained, slightly argillaceous, gray or brown, porous, and often cross bedded. The sheet sandstone facies is up to 20 feet (6.1 m) thick, but the channel facies may exceed 100 feet (30 m) in thickness. The channel is eroded into older rock units, in places as far as the Colchester (No. 2) Coal. More often only the Herrin (No. 6) Coal and its roof strata are eroded. Some branches of the channel system can be traced for more than 100 miles (160 km), and the channel width may reach two miles (3.2 km).

The Copperas Creek Sandstone Member occurs in western and northwestern Illinois and exhibits characteristics equivalent to the Anvil Rock Sandstone, with which it has been correlated. For this report it has not been studied because it occurs outside the area of current underground mining.

Bankston Fork Limestone Member

The Bankston Fork Limestone (Cady, 1926) can be traced through most of the Illinois Basin, but it has not been definitely identified west or north of the Illinois River. In the east and southeast of the basin, it correlates to the Universal Limestone Member of Indiana, and it is present in western Kentucky. The Bankston Fork Limestone consists of one or more benches of occasionally slightly dolomitic limestones. The limestone benches are separated by calcareous shales. One to three impure limestone benches are most common. Where the Anvil Rock Sandstone is thick, the limestones are frequently absent. In St. Clair and in Vermilion Counties, as many as seven limestone benches reaching about 20 feet (6 m) total thickness have been reported. The Bankston Fork Limestone commonly is three to eight feet (0.9 to 2.45 m) and generally less than 6 feet (1.8 m) thick. Although persistent throughout the Illinois Basin, local rapid changes in thickness and purity and pinch-outs have been found. Its fauna, composed mainly of brachiopods and fusulinids, implies open-marine environment (Willman et al., 1975).

The Bankston Fork Limestone normally overlies the Lawson Shale or the Anvil Rock Sandstone and is overlain by strata of medium-gray or greenish-gray shales, which locally include the Allenby Coal Member and some associated underclay, and the Galum Limestone Member, which may be considered an underclay limestone of the Danville (No. 7) Coal Member (fig. 1 and fig. 6).

Younger strata

Strata above the Bankston Fork Limestone Member have little influence on roof stability in underground coal mines, and so are not treated in this report. For details on rock units above the Bankston Fork Limestone, the reader is referred to Willman et al. (1975).

TECHNIQUES EMPLOYED

A variety of work techniques have been employed to investigate, collect data on, and properly describe the characteristics and parameters of geologic features that significantly influence the stability of the Herrin (No. 6) Coal roof. The main methods applied were:

1. Regional mapping using rock stratigraphic data base and computer graphics
2. Detailed mapping of selected study areas in underground mines
3. Close-range photogrammetry
4. Core drilling in underground mines
5. Laboratory testing of drill cores
6. Clay-mineralogy studies

Regional mapping using rock stratigraphic data base and computer graphics

Techniques of computer graphics were used extensively throughout this study. To implement these techniques, the geologist specifies the map area, the map scale, the value to be contoured, the contour interval, and any special parameter. Output can be in form of a map produced by a line printer or a plotter showing legal boundaries, data points, and contour lines. Computer graphics were used to produce three tools: (1) regional isopach and structural maps of selected rock-stratigraphic units, (2) detailed coal structure maps of the mines studied, and (3) graphs depicting a variety of geologic relationships.

The maps were computer-generated using GEOMAPS, a program package developed by the Illinois State Geological Survey. GEOMAPS is the union of two mapping programs—ILLIMAP, developed by the Illinois State Geological Survey (Swann et al., 1970) and STAMPEDE, developed by IBM (IBM Corporation, 1968). ILLIMAP can produce a Calcomp plotter base map of any specified area in Illinois at any selected scale, limited only by the plotter size. In addition it will plot data points on the base map and label them with well number, lithologic symbol, or formation thickness. STAMPEDE is used to generate contour maps which can be plotted by computer on an ILLIMAP base. Experience has shown that in most cases, STAMPEDE can more rapidly produce maps equivalent to or at least comparable to those drawn by geologists, given the same data.

REGIONAL MAPS

Regional maps were generated to show general geologic trends throughout a large area of southern Illinois (fig. 9). A data base was established using the Illinois State Geological Survey's extensive well records library. Logs were selected which contained accurate information on the thickness of the Herrin (No. 6) Coal and the rock units above it, to the horizon of the Piasa Limestone (fig. 6). Thickness and lithology of identifiable units for each log were entered on data forms (fig. 10) and stored on computer disk. Types

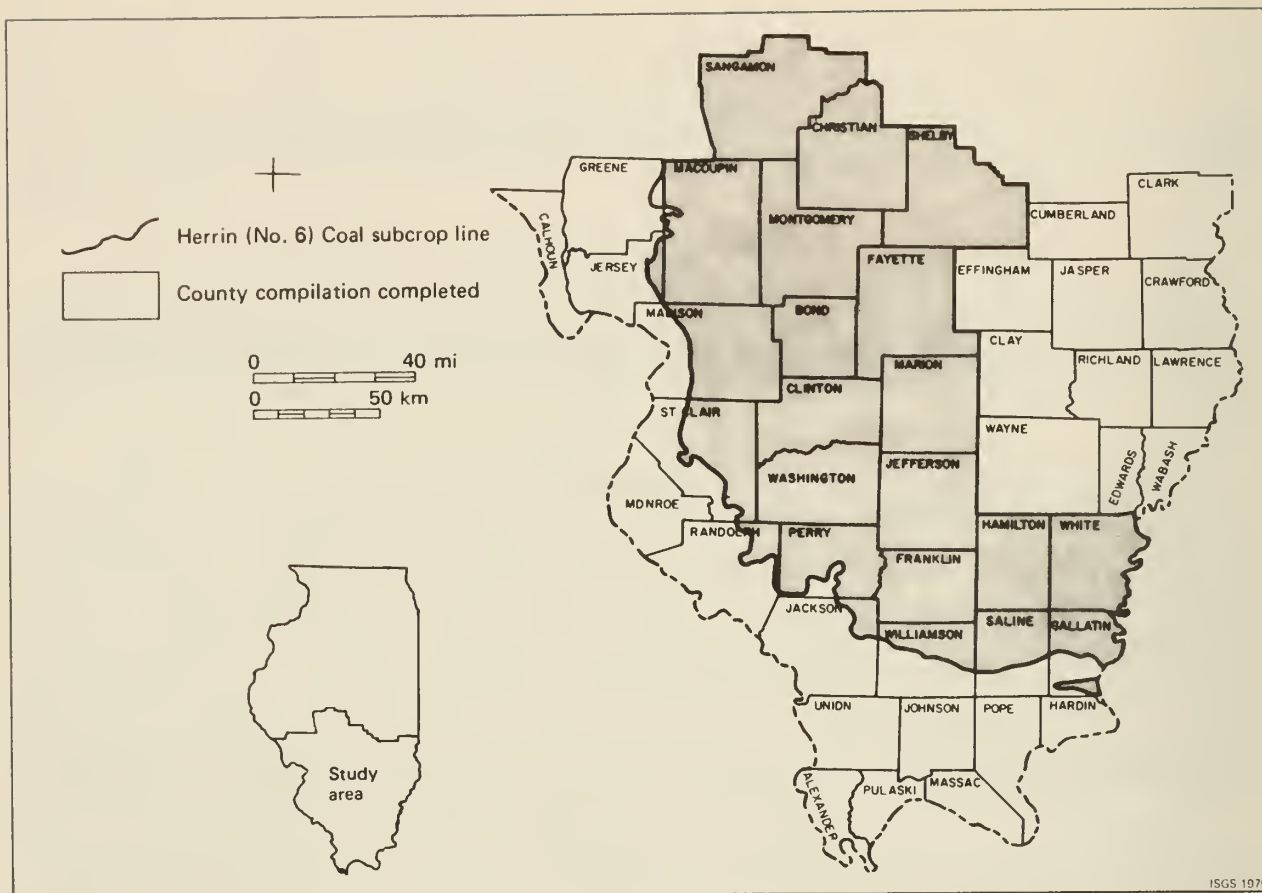


Figure 9. Area in the southern half of Illinois for which data on thickness and facies of roof strata above the Herrin (No. 6) Coal extending up to the Piasa Limestone were collected and compiled in computer-processible form.

HERRIN (NO. 6) ROOF STUDY—DATA ENTRY FORM

CARD #2

C A R D N O.	C O. C O D E	County No. of Datum Point	1		2		3		4		5		6		7		8		9		10		11		12
			HERRIN (NO. 6) COAL	ANNA SHALE	BRERETON LS.	SHALE ABOVE BRERETON LS.	JAMESTOWN COAL	CONANT LS.	ANVIL ROCK SS. AND LAWSON SH.	BAKESTON PORK LS.	SHALE ABOVE BAKESTON PORK LS.	ALLENBY COAL	SHALE ABOVE ALLENBY COAL	ENEADY SHALE AND WALSH- VILLE CHANNEL											
			Thick- ness	Lith Symb	Thick- ness	Lith Symb	Thick- ness	Lith Symb	Thick- ness	Lith Symb	Thick- ness	Lith Symb	Thick- ness	Lith Symb	Thick- ness	Lith Symb	Thick- ness	Lith Symb	Thick- ness	Lith Symb	Thick- ness	Lith Symb	Thick- ness	Lith Symb	
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Figure 10. Data entry form for the Herrin (No. 6) roof study.

of logs used included core descriptions, drillers' logs, and electric logs. An average datum-point density of about 18 logs per township or 1 hole per 2 square miles was chosen, which, in relation to the consistency, continuity, and slight variability of the coal and its roof strata and in accordance with the scale of the maps, was necessary and sufficient. In areas of special interest, such as around mine study areas, all available data points, commonly ranging from one to five per section, were used. The data base was developed so that it could be added to or deleted from as necessary.

Once the data base was completed, isopach and structural maps of the rock units composing the roof of the Herrin (No. 6) Coal were generated. These were used to determine the regional extent of units, patterns of deposition, structures, and any relationships that might exist between two or more lithologic units or between lithologic units and structural features. In addition, maps of particular interest to mining engineers were generated. For instance, maps were made of the interval from the top of the coal up to the first limestone greater than 2 feet in thickness. Such maps can be useful in developing a roof bolting plan.

STRUCTURAL MAPS OF MINE AREAS

Detailed structural contour maps, on which the elevations were contoured mostly on top of coal, were produced for each mine studied. These proved to be useful for: the recognition of overall trends (strike and dip) and geologic anomalies, locating areas within the mines for further specific studies, and the interpretation and interpolation of field observations. In some cases, these maps provided valuable clues in deciphering features observed in the mines. Data for the maps were obtained by digitizing mine survey maps or by entering the original survey data on punch cards. Survey points were commonly 50 to 100 feet (15 to 30 m) apart for the entire length of at least one entry in each panel or set of mains. They provided excellent control on the coal structure and produced detailed and reliable computer-drawn maps.

Detailed geologic mapping of selected study areas in underground mines

All significant geologic features over the selected study areas were mapped to determine the influence of geologic factors on the stability of roof strata in the coal mines. The study areas had to be large enough (1) to define lithologic and structural trends in distribution, orientation, and frequency, (2) to interpret their significance, and (3) to be able to interpolate or extrapolate significant characteristics over larger areas.

The mapping for this study required more than a year of field work. For most purposes a scale of about 1:1,200 (1 inch = 100 feet) was found to be best. Some geologically complex areas were mapped on larger scales. The coal company provided maps (1:1,200) showing entries and panels, rooms, and pillars which were used as base maps for detailed mapping. The precision of these maps varied widely from mine to mine. Many features cannot be drawn adequately on a map of any scale, particularly complexly faulted areas, horizontal shear planes, stratigraphic sequences, and many unusual or unique structural features. These are portrayed and described in cross sections, sketches, diagrams, photos, and field notes. Numbers drawn on the maps refer to the field notes. The final

lithologic, structural, and roof fall compilation maps are grouped by study areas in the section on the maps.

Close-range photogrammetry

Close-range photogrammetry is a practical means of acquiring data in inaccessible areas such as roof falls in underground mines or highwalls of strip mines (cf. Brandow et al., 1975 and 1976). The photogrammetric technique was used to collect information on the orientation of various kinds of geologic structural surfaces, such as cleats in coal, joints in the associated rocks, faults, spacing of fracture surfaces, and thickness and shape of various geologic bodies. An important advantage of the technique is the preservation of the spatial relation of exposed structural surfaces (for instance, of a roof fall) for future investigation. The method was also used to map an advancing highwall in a strip mine to obtain structural data in sections which will ultimately make available a three-dimensional model of the shape of the rock bodies in that area. Photogrammetry shortens the time required for making measurements and allows the geologist more time for evaluating the geologic significance of single structural elements. The photographs together with the geologist's notes furnish a complete permanent record that can be retrieved and analyzed at any time.

OBJECT SPACE CONTROL AND ACQUISITIONS OF PHOTOGRAPHY

An object space control system must be established to determine the appropriate parameters necessary to transform photographic measurements to useful geologic data. An arbitrary coordinate system rotated for alignment with geographic coordinate axes was used to ascertain surface orientation of structural elements in roof fall areas (cf. Brandow et al., 1975). Although an arbitrary coordinate system is sufficient for obtaining data in roof fall areas, a different approach is required to obtain a three-dimensional model of the geographic position and the shape of rock bodies in strip mines. In acquiring a digital model of a strip mine by mapping the advancing highwall, measurements from photography taken at various times as the highwall advances must be transformed to a common coordinate system.

Close-range photogrammetry has been used to collect structural geologic data with metric cameras. Photography for both phases of this project was completed with a tripod-mounted Yashica C 2 $\frac{1}{4}$ -x-2 $\frac{1}{4}$ inch camera with a Yashikor 80mm, f/3.5 lens and a Hasselblad, model 500 C/M camera equipped with a 50 mm, f/4 lens. Stereopairs were exposed with the cameras' optical axes nearly parallel to each other and approximately normal to the base line between exposure stations. A base-to-distance ratio of about 1:3 provided an overlap of more than 60 percent.

MENSURATION AND DATA REDUCTION

Observations were made on the original negatives with a WILD STK stereo-comparator and reduced by a computerized, completely analytical approach. The direct linear transformation (DLT) was used to establish the relation between the measured comparator coordinates and the object-space coordinates of the control points. The development of equations used by DLT and a documented computer program are available (Abel-Aziz and Karara, 1973; Marzan and Karara, 1975).

Core drilling in underground mines

Core drilling was used to supplement geologic mapping, especially in areas where roof falls were so scarce or shallow that strata above the immediate roof could not be examined. Drilling also provided samples that could be tested for various mechanical rock properties (e.g., strength and deformability). A Chicago pneumatic blast hole drill, model CP 65 equipped with a diamond coring bit on NX drill steel, was used to drill six underground test holes, all in study area 7, mine C. The mine provided a Joy compressor for air circulation. Three test holes, each about 20 feet in length, were drilled into the roof; one was drilled horizontally in coal, and two horizontally into a large sandstone roll. The three roof cores were drilled upwards, ten degrees from the vertical, to allow an orientation of the core samples. All samples from the three vertical holes were logged and wrapped to preserve moisture.

Core testing

The samples were removed from their aluminum foil wrappers and covered with thin acetate to minimize the loss or gain of water in the samples during cutting. Samples were then cut with a trim saw and the ends were lapped to obtain a length-to-diameter ratio of 2.00 ± 0.02 and a tolerance for non-parallelism of the ends of ± 0.0025 in. No effort was made to preserve the water content of the samples during laboratory testing.

Axial loading was provided by a 100-ton hydraulic ram driven by a Donath multiple-rate pump which provided constant strain conditions; the rate of loading for most of the tests was 6,000 lb per minute (approximately six minutes to failure). The loading column was equipped with a spherical seat to minimize eccentric loading. No caps of any type were used, and the steel platens on both ends had a radius of approximately 0.25 in. larger than that of the samples. The larger platens were necessary to monitor axial displacements. Axial displacements were monitored by two methods: (1) two transducers with infinite resolution were mounted opposite to each other on the loading platens and (2) two samples (H-3 #32 and H-3 #35) were instrumented with two one-inch, moisture-proof, self-temperature-compensated electrical resistance strain gauges mounted at midpoint on the sample and diametrically opposed. These samples were tested first for deformation only and a comparison was made between the moduli obtained by the two methods.

Force-displacement data were recorded graphically by means of a Hewlett-Packard X-Y plotter and as digital voltage by means of a scanning PDP-8 computer. The use of the computer provided a more accurate record, but in all cases the computer data gave the same results as the graphical record. The precision of the graphical record was ± 0.001 in. for displacements and ± 40 lb for force.

The Young's modulus was obtained as a tangent modulus at 50 percent of the ultimate strength. The ultimate strength was found by dividing the ultimate axial force by the area of core perpendicular to its axis. We believe that the computed values of modulus and uniaxial strength are significant only to the nearest 10^5 psi and 10^2 psi, respectively.

Techniques employed in clay mineralogy studies of various roof and floor rocks

The rocks that make up the immediate roof or floor of the Herrin (No. 6) Coal include limestones, shales, claystones, mudstones, siltstones, sandstones, and coal (fig. 6), all of which have wide ranges of physical and chemical properties. The properties of shales, the most common immediate roof rock, are controlled in part by: (1) grain and particle size of components; (2) type of cement and matrix of rock; (3) contents (percentage) of clay minerals; (4) variety and combination of clay minerals in the rock; (5) orientation of the various clay minerals in the rock; (6) structure and texture of the rock resulting from the other factors.

Basic clay minerals considered were illite, kaolinite, chlorite, expandable mixed-structure clay minerals, and montmorillonite. The petrographic terms for the tested silicious clastic rocks were used according to their grain or particle sizes (fig. 11). The techniques applied to obtain necessary data are mechanical, optical, and chemical analyses; radiography; and x-ray diffraction (see Grim et al., 1957).

MECHANICAL, CHEMICAL, AND OPTICAL ANALYSES

Samples were usually described and labeled before analysis, and, if desired or needed, the cleaned but unprocessed samples were photographed (fig. 12). Specimens to be analyzed were then sawed into slabs, thin sectioned, polished, crushed, pulverized, or otherwise prepared for further analysis.

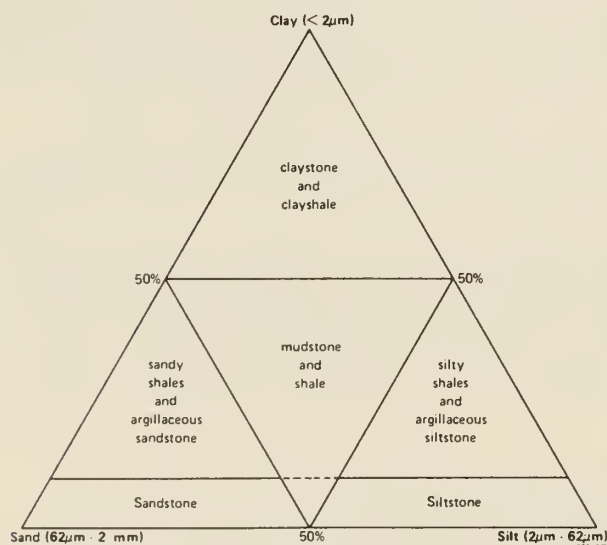


Figure 11. Classification chart for siliceous clastic rock types.

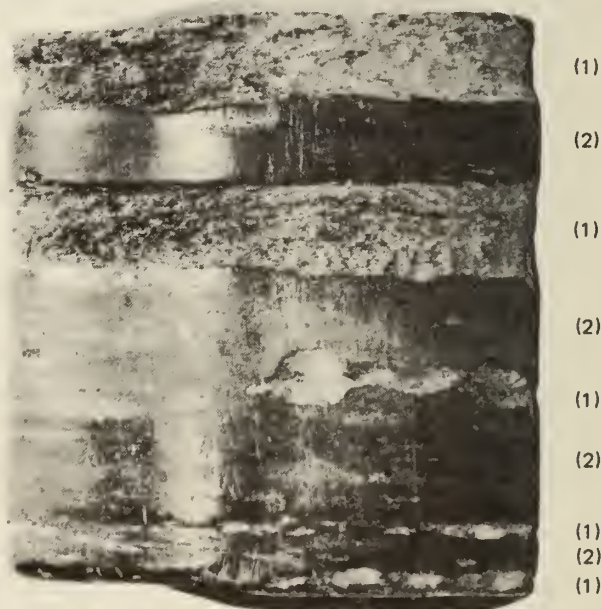


Figure 12. Dark-gray shale from a 2-1/8-inch core. (1) Shale was eroded by drilling fluid, (2) shale was not eroded due to its higher density and greater content of clay minerals parallel to bedding. (Anna Shale from Gallatin County, southeastern Illinois.)

Grain size and particle size for clay ($<2\ \mu\text{m}$), silt ($2\ \mu\text{m}$ to $62\ \mu\text{m}$), sand ($62\ \mu\text{m}$ to $2\ \text{mm}$), and gravel ($>2\ \text{mm}$) were commonly determined by pipette and sieving. The nonclay mineral components were not studied in further detail with the prominent exception of their textural attributes and their association with the clay minerals, which were observed with a microscope.

Other mechanical analyses, such as determination of Atterberg limits (liquid limit, plastic limit, plasticity index) and the activity index, provided rock index data, which also helped to quantify certain types of roof rocks. The Atterberg limits were obtained according to the definition and procedure of Allen (1942) and White (1949). Samples of silty shales, sandy shales, or fissile black shales that did not slake to produce sufficient plasticity to obtain Atterberg limits, after having been processed in water for days or even weeks, were all simply marked "too sandy." The activity is defined as directly proportional to the plasticity index and inversely proportional to the quantity of particles smaller than $2\ \mu\text{m}$. Thus, the activity index provides an arbitrary method of comparing the plasticity of rocks with different clay components and varying clay quantities. Chemical analysis was performed according to standard methods by members of the chemical group of the Illinois State Geological Survey. Samples were analyzed for CO_2 , SO_4 , organic carbon, pyritic sulfur, total sulfur, and boron. Microstructural and textural studies and identification of coarse-grained minerals found in the heavy liquid separations of the silt and sand fractions were also obtained by standard techniques employing microscopes.

RADIOGRAPHY AND X-RAY DIFFRACTION ANALYSES

Radiography provides an x-ray photo of a sample and is mainly used to show vague and indeterminate or otherwise even invisible structural features. To obtain a radiograph, a plain slab of rock is cut $6\ \text{mm}$ (about $\frac{1}{4}\ \text{in.}$) thick, perpendicular to bedding or in any other orientation selected. It is then placed on a film indicating any selected orientation with a lead marker (arrow), which is placed on the same film. An x-ray beam sent through the slab of rock exposes the underlying film according to the energy-filtering within the rock.

X-ray diffraction is used for determining clay minerals and the orientation of the clay minerals in argillaceous rocks. Over the past 25 years both the General Electric XRD3 spectrometer, with copper radiation and nickel filter, and the Norelco X-ray spectrometer, with copper radiation and a graphite crystal monochromator, have been most commonly applied. For clay mineral identification, particles $<2\ \mu\text{m}$ were separated from the rock samples by wet sedimentation methods. With the $<2\text{-}\mu\text{m}$ material on glass slides, one specimen from each rock sample was placed in an ethylene glycol atmosphere for a week and then x-rayed from $2\frac{1}{2}^\circ$ to $40^\circ 2\theta$. After the first x-raying, the same slide with the $<2\text{-}\mu\text{m}$ material was heated for one hour at 300°C and x-rayed again from $2\frac{1}{2}^\circ$ to $22\frac{1}{2}^\circ 2\theta$. From the diffraction data the clay minerals were determined in parts of 10 using the form in figure 13.

The orientation of the clay minerals also was determined by x-ray diffraction of thin sections of rock, cut parallel and perpendicular to the lamination or bedding. The following formula was used to determine the orientation index of the samples (figs. 14 and 15).

$$\text{Orientation index} = \frac{19.8^\circ 2\theta \text{ peak area}}{\frac{5^\circ}{4} + \frac{5.5^\circ \text{ to } 6.5^\circ - 6.1^\circ}{3} + \frac{6.5^\circ \text{ to } 7.5^\circ}{2} + \frac{7.5^\circ \text{ to } 8.8^\circ}{1} + 12.4^\circ 2\theta \text{ peak areas}}$$

SAMPLE NO. _____

Location _____

Depth _____ to _____ Date _____

I 1.0 = _____

$$\frac{M_1^g}{4I_1^g} = M = \text{_____}$$

If M is present $I+M+EX_1^h$ _____ - $\frac{M_1^g}{4} = I+EX_1^h$

$$I+EX_1^h$$
 _____ - I_1^g _____ = $\frac{EX_1^h}{I_1^g}$ - EX _____ = _____
$$\frac{K_2}{2C_4} = \text{_____} \times (\#1) = K = \text{_____}$$

When chlorite is not present $\frac{K_1^h}{I_1^g} = K = \text{_____}$

$$(\#1) \frac{C_3^h}{I_2^g} = C = \text{_____}$$

Calcite _____	Pyrite _____	EX = Expandable clay minerals I = Illite C = Chlorite K = Kaolinite M = Montmorillonite
Dolomite _____	Siderite _____	
Quartz _____	Gypsum _____	
Feldspar _____	Others _____	
P _____		
K _____		

h = Heated 300°C for 1 hour
g = Treated in ethylene glycol atmosphere for 2 or more days
1,2,3, and 4 subscript are 1st, 2nd, 3rd, and 4th orders in C-direction

Figure 13. Calculation form for mineral contents in argillaceous sediments.

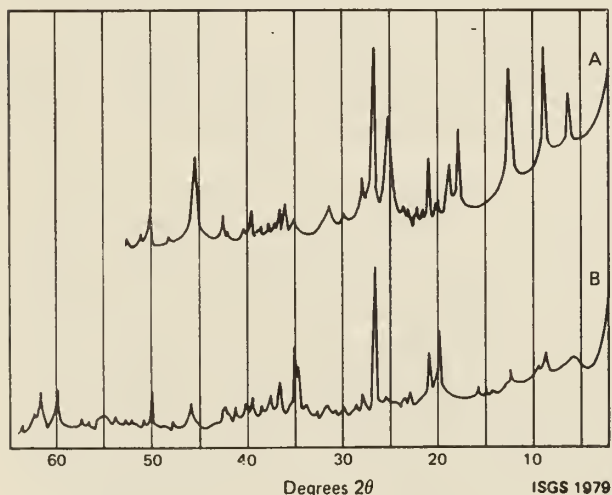


Figure 14. Diffractograms of a well-laminated shale. Sample A was cut parallel to bedding. High diffraction peaks at 6.1, 8.8, and 12.4° 2θ and very small peak at 20° and 35° 2θ indicate that most of the diffraction came from larger faces of the clay crystals. Sample B cut perpendicular to bedding has low peaks between 5 and 15° 2θ and higher peaks at 20 and 35° 2θ, showing that most of the diffraction came from the edges of the clay crystals. Result: clay crystals with preferred orientation parallel to bedding and lamination. (Samples: gray shale from Edgar County.)

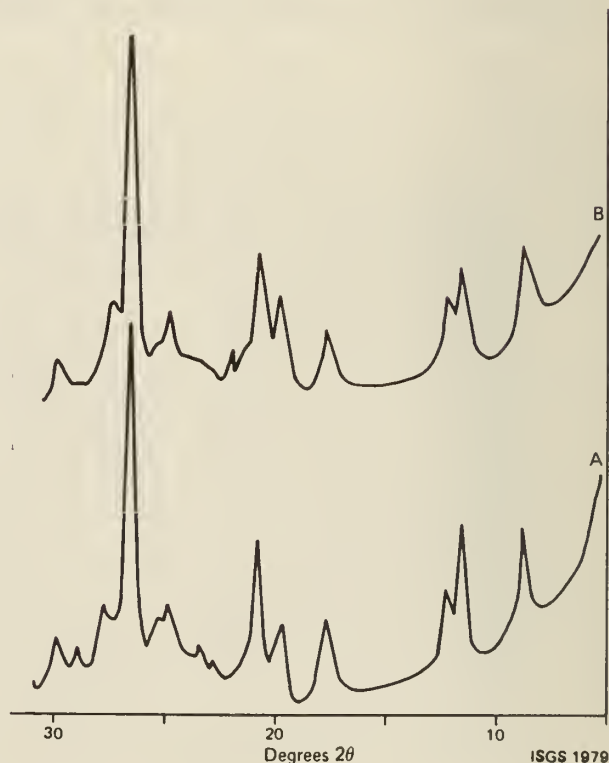


Figure 15. Diffractograms of a claystone in which sections of rock were cut parallel to bedding (A) and perpendicular to the bedding (B). The diffraction peaks in both sections are of about equal height, indicating randomly oriented clay crystals. (Sample: gray shale [mudstone] from Edgar County.)

ROOF TYPES OF THE HERRIN (NO. 6) COAL MEMBER IN ILLINOIS

The Herrin (No. 6) Coal in Illinois is overlain primarily by two sequences of roof rock: the gray shale roof and the black shale-limestone roof. These roof rock type names should be used neither synonymously nor interchangeably with the names of their lithologic contents or the names of associated rock stratigraphic units (members); the distinction between engineering characteristics and petrologic or geologic data must remain clear. The gray shale roof consists of gray shales, siltstones, and sandstones, above which limestones occur but have only local influence on the stability of the immediate roof. These lithologies are usually characteristic of the Energy Shale and sediments deposited in the Walshville channel. The black shale-limestone roof normally contains black shale and limestone immediately above the coal and is overlain by mottled shale and some minor coals and limestones. Rock-stratigraphic units of this roof type are the Anna Shale (at base), the Brereton Limestone, the Jamestown Coal, the Conant Limestone, the Lawson Shale, the Anvil Rock Sandstone, and the Bankston Fork Limestone (fig. 6). The black shale-limestone roof type prevails over almost 90 percent of the area of distribution of Herrin (No. 6) Coal, whereas the gray shale roof has been found only in small areas adjacent to two paleochannel systems—the Walshville channel (fig. 5) and the Anvil Rock channel.

Gray shale roof types

Channels in the Desmoinesian Series not only coexisted with the swamps, but they also formed and persisted after the accumulation of coal-forming sediments. The Walshville channel (Johnson, 1972) existed contemporaneously with the deposition of Herrin (No. 6) Coal and possibly through the time of deposition of the Anna Shale. Whether there was a continuation of channeling into younger periods has not been proved because of a probable interference with the younger Anvil Rock channel. Both channels interrupt the Herrin (No. 6) Coal in certain parts of Illinois. Sandstones and siltstones deposited in both channel systems also have been found in the immediate roof of the Herrin (No. 6) Coal. Sandstones and siltstones deposited in both are thought to grade vertically and laterally into gray silty shales and gray shales, which in places directly overlie the Herrin (No. 6) Coal. The gray shale roof types consist of different types of gray shales, silty shales, and siltstones, and, in a few places, sandstones. Also considered with the gray shale roof types are the transitional types of gray shale-black shale-limestone roof. Although a number of techniques and a variation of methods in the mining procedures may influence the behavior of the mine roof, roof stability in Illinois coal mines depends on two major geologic factors: the lithology and facies of the roof strata, and the structural anomalies and deformational features.

LITHOLOGY AND FACIES OF THE GRAY SHALE ROOF TYPES

Lithology and facies variation of roof strata are the basic influences on mine roof behavior and have had a major effect upon structural anomalies and deformational features ever since sedimentation ended. Lithology of roof strata has to be investigated, mapped, and described thoroughly, because the lithology is a primary factor determining roof stability. Since mining methods in some mines call for leaving top coal underneath the roof rocks, "top coal" is considered here as part of the roof strata. Normally, however, the gray shale roof

types can be classified according to lithologies and facies of (1) basal carbonaceous shale and siltstone with plant debris, (2) dark-gray shale, (3) medium-gray shale, (4) siltstones and sandstones, and (5) gray shale-black shale-limestone roof transition.

Top coal

Top coal, also called skin coal, is coal purposely left in the roof during mining. In many mines of Illinois, and particularly those in the thick Herrin (No. 6) Coal of the "Quality Circle" of southern Illinois, it is common practice to leave top coal several inches up to two feet thick (15 to 60 cm). Top coal is left in the roof for a number of reasons:

1. The cutting height of the boring type of continuous miner is limited by the height of the machine. Thus, when the coal is higher than the machine, either top or bottom coal, or both, must be left. Boring machines leave an entry characterized by arched ribs (fig. 16), which are less prone to rash than the vertical rib made by a ripper type of continuous miner (fig. 17). In thick coal (more than ten feet), even a ripper may be forced to leave top or bottom coal. Where soft bottoms or floor heaving are encountered, bottom coal is left. Otherwise, miners generally leave top coal.
2. The quality of the coal at the bottom or at the top of the seam may be low as it grades into floor or roof rock.
3. Miners like to hear the roof "talk," especially in panels that will be pillared. Top coal is thought to give audible warning of impending roof falls.
4. Convergence of floor and roof, especially sagging and breakage in the roof, becomes more visible as top coal breaks along the center of the roof sag and slabs down.
5. Top coal is left to protect moisture-sensitive roof shales from exposure to mine air. Many shales disintegrate when exposed to changing humidity, especially near air intakes (Augenbaugh, Skudrzyk, and Bruzewski, 1975).
6. Where the seam is thick enough, top coal may permit driving of more regular openings under roof shales that have an irregular contact with the coal. This is especially true in areas of rolls (protrusions of roof material into the coal). At mine B, entries are usually driven without leaving top coal, but at least one foot of top coal is left in the panels. The main argument in favor of leaving top coal is to provide roof control, but since rolls are common in this mine, the thickness of top coal varies considerably. Under rolls, the miner cuts into roof rock without leaving top coal, but in adjacent areas much more top coal than necessary is left.
7. Some miners leave top coal simply because they feel it improves roof control.

The main argument against leaving top coal is that it prevents inspection of the immediate roof. In many cases such inspection would reveal that the

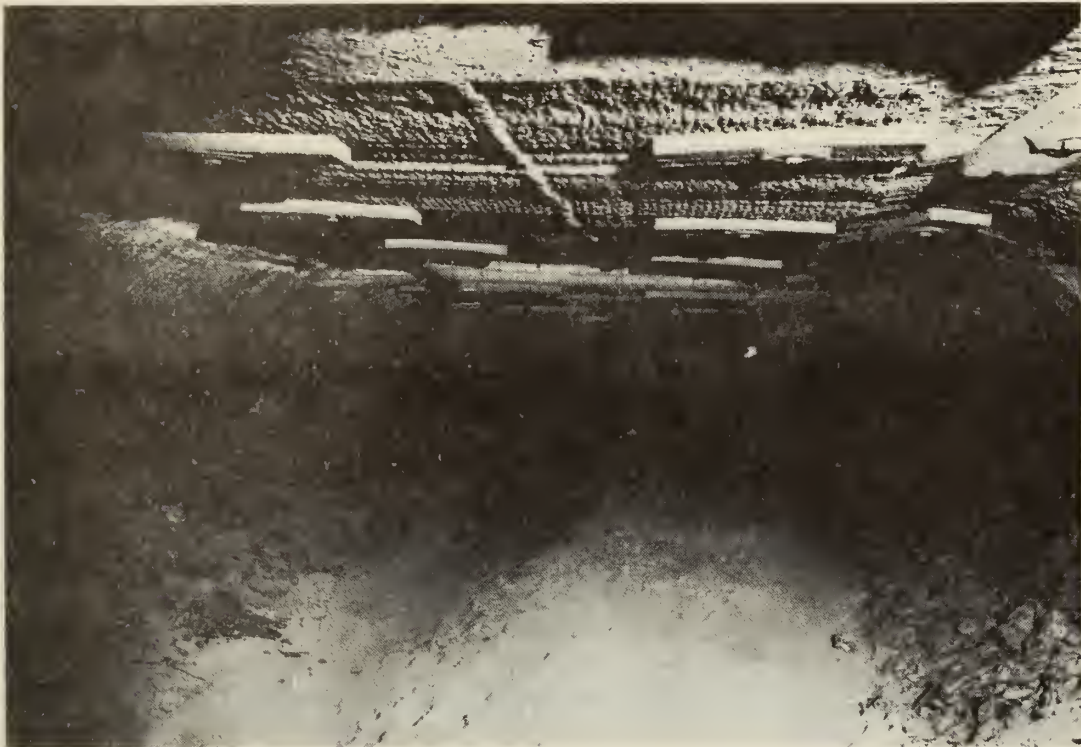


Figure 16. Top coal left in an entry cut by a Marietta boring type of continuous miner. Cutting height is limited by height of machine. Arched ribs in transition to roof and floor decrease intensity of rib rashing.



Figure 17. Top coal left in an entry cut by a ripper type of continuous miner. Although the cutting height is variable and more coal can be produced, the hazard of rib rashing along straight vertical ribs is greater (left side of photo).

roof would be good, or excellent, with or without top coal. Large portions of mines in the "Quality Circle" have excellent roof conditions; over time, only the top coal up to the roof shale peels away. Top coal hides the roof rock and the dangers that lie within. Many irregularities in the roof, such as minor faults, slips, and rolls, may affect only the uppermost layer of the coal. In many cases the hidden slip or roll causes a fall that could have been prevented if the danger had been visible and additional roof support had been installed. Top coal would have hidden even the shear body in mine B, study area 5, until the roof caved in. Although many good reasons exist for leaving top coal, indiscriminate use should be avoided because roof control may be neglected rather than improved.

Basal carbonaceous shales and siltstones with plant debris

Thin strata of carbonaceous shales (in places having streaks of bony coal), silty shales, or siltstones that have plant fragments and thin sheets of plant debris on bedding surfaces form a layer, variable in thickness, that averages a few inches, but ranges to as much as about two feet (60 cm). This layer is found underneath the other facies of the gray-shale roof and, where present, forms the immediate roof of the Herrin (No. 6) Coal. This carbonaceous basal layer is typically an irregular interlamination of dark-gray flaky shale or medium-gray silty shale or siltstone, and carbonaceous plant fragments or even bony coal. Basal siltstone and silty shales occur most often beneath large sandstone and siltstone bodies or sheets. The fine-grained shales often contain impressions of fragile leaves and fern fronds, whereas the coarser-grained silty shales and siltstones more often contain larger coalified plant fragments, twigs, stems, and, occasionally, large tree trunks.

The basal layer tends to break, slab, or flake loose from overlying sediments. The basal carbonaceous strata are usually not thick enough to be of major influence and concern for roof control; however, in some places tree stems and slabs large enough to injure miners may fall from this layer, as in study area 9 of mine D and study area 4 of mine B, for example.

In study area 4 of mine B, we measured the orientation of 115 tree trunks to see if a preferred orientation could be recognized that might in turn be related to other sedimentological and structural directional features (fig. 18). Although the northeast-southwest trend is slightly more represented than other directional trends, no clear preference is recognizable.

Dark-gray shale facies

The dark-gray shale facies of the Energy Shale is stratigraphically the lowest major facies. Where the basal carbonaceous shales and siltstones having plant debris are absent, it forms the immediate roof of the coal seam over large areas. It consists of dark-gray, almost black shale. The shale is hard, smooth, usually well-laminated, and carbonaceous. Weathering tends to accentuate the fine lamination; the shale then usually assumes a brownish cast. The darker shale derives its coloring from finely dispersed coaly material and from numerous tiny carbonaceous streaks. The shale often contains thin coal stringers. Thin discontinuous sideritic laminations are common. Thin sideritic nodules are commonly concentrated in layers, but may also occur scattered throughout where the shale is more homogeneous, massive, and less laminated. Small pectinoid pelecypods and Anthracosiidae indicate deposition

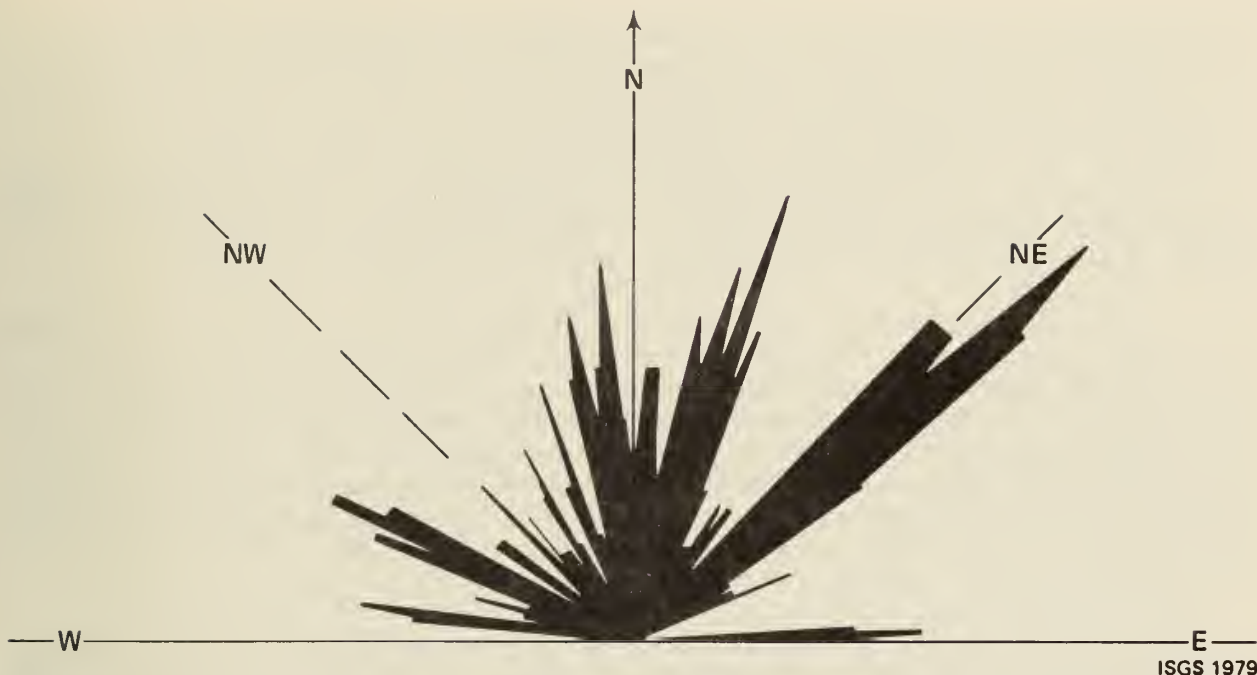


Figure 18. Rose diagram of orientation of 115 tree trunk imprints observed in basal carbonaceous shales and siltstones, immediate roof rock of Herrin (No. 6) Coal in study area 4 of mine B. Main trend is northeast-southwest, but a preferred orientation is not apparent.

in fresh to brackish water. Plant impressions are more abundant than mollusk impressions. The rock resembles lithologies of the Anna Shale, but generally has lighter color, is less fissile, and contains different fossils. It is more argillaceous and finer grained than the other lithologies of the Energy Shale and indicates an environment characterized by slow and little deposition in quiet water. The strata of the dark-gray shale facies average one to two feet (30 to 60 cm) in thickness and rarely reach ten feet (3 m). In study area 5, the dark-gray shale varies in thickness between 0.2 and 5 feet (6 cm and 1.5 m); most commonly it is 0.3 to 2.0 feet (9 to 60 cm) thick. In study area 4 at mine B, as well as in other mines in southern Illinois, the recorded thickness shows the same range.

Even though the dark-gray shale is thin, it is widespread in mines B, H, I, and others. In study area 4 at mine B, it forms the immediate roof over 70 to 80 percent of the area. Farther to the east, in study area 5, the percentage is 50 to 60. The dark-gray shale underlies a medium-gray shale. The contact is normally sharp and conformable, but in places appears to be gradational. Where the dark-gray shale is absent, the medium-gray shale directly overlies the coal seam. The regional boundaries on top of the coal are irregular or lobate, and the dark-gray shale thins gradually toward this boundary. It was noted, especially in mine B, that the dark-gray shale pinches out over structural highs in the coal seam, and the overlying unit, normally medium-gray shale, forms the immediate roof. Although the dark-gray shale facies occurs in almost all mines in the "Quality Circle," it was not found in study areas 6 and 7 of mine C.

Among the various lithologies of the gray shale roof type, the dark-gray shale most often exhibits joints. Vertical joints are in places as well-developed

and as closely-spaced as joints in the Anna Shale (described in detail in a following section). More often, joints are about one to several feet apart and their influence on roof stability is minor. A trend of joints N60°-80°E prevails both in study areas 4 and 5 of mine B and in other mines of the "Quality Circle." Most of the joints in the dark-gray shale are confined to that layer and do not penetrate into the overlying, softer, medium-gray shales. Development of joints is dependent on lithology; often it is possible to distinguish different lithologies by the characteristics of joints.

Although small-scale, soft-sediment deformational features, boudinagelike pull-apart structures, minor shear surfaces, and microfaults have been observed in the dark-gray shale, an almost total absence of slump structures and rolls has been noted. Major deformational features, however, which affect the dark-gray shale, apparently result from a more regional deformational influence, e.g., large landslidelike shear bodies like those mapped in study area 5 of mine B, as well as sliding and displacement of blocks in genetic relations to major faults systems like the Rend Lake Fault System (as mapped in mine H) or the Cottage Grove Fault System (as mapped in mine I).

The dark-gray shale has rather variable roof stability. In some areas, as in most of study area 4, these strata form a stable roof that has an even surface. Elsewhere, the dark-gray shale is a "draw slate" (miners' term) that falls or must be taken down immediately after mining. Major roof falls can occur where the dark-gray shale is thick—four feet (122 cm) or more. Large falls at C-4 in study area 4 (see fig. 139, p. 153) and C-2 and H-2 (see fig. 140, p. 154) in area 5 both of mine B entirely involve thick dark-gray shale, which in the latter area is about ten feet (3 m) thick. Thin (a foot or less) dark-gray shale is less a hazard, though slabbing is common along joint planes, and the above-mentioned fossil kettle bottoms may fall.

Medium-gray shale facies

The dominant facies of the Energy Shale is a medium-gray shale, which is usually firm, finely micaceous, and in places slightly carbonaceous, and contains abundant sideritic bands, nodules, and lenses. Small coaly fragments and plant impressions are numerous, especially in the lower part. The medium-gray shale has a coarser grain than the dark-gray shale. It contains abundant quartz grains, and is often silty shale, which locally may grade into a siltstone or sandstone. Exposures in mines and drill-hole data show that the shale may attain a thickness of 50 feet (15 m) or more. The medium-gray shale facies is so dominant that the terms "gray shale" and "Energy Shale" often are used interchangeably in discussing the roof of the Herrin (No. 6) Coal.

The medium-gray shale contains thicker and fainter laminations than the underlying dark-gray shale. The carbonaceous material in the dark-gray shale consists of tiny coal streaks, thin flakes, and fine, carbonaceous fragments and grains that were corroded during transport and that are scattered within the medium-gray shale.

X-ray diffraction patterns of medium-gray shale samples indicate that the clay mineralogy varies. The medium-gray shale does not contain as much expandable clay mineral as the dark-gray shale, but kaolinite and illite are present in both shales. Hard, generally nodular concretions are only occasional

found in the medium-gray shale, just above the top of the coal. Few of these features are shown in the study areas, but large concentrations were observed in mine B outside the study areas. Two types of concretions occur. The most common types are very hard gray limestone "balls," about a foot (0.3 m) in diameter. They often contain open fractures that are lined by clear crystalline quartz or calcite. Less common are large oval nodules or lenticular bodies of fine-grained spherulitic pyrite. These are extremely hard, difficult to cut with a continuous miner, and, like the limestone concretions, constitute a minor roof hazard. They are, however, not nearly as serious a danger as the black concretions abundant in the Anna Shale.

Bedding planes, especially in the silty portions of the medium-gray shales, are in many cases coated with a film of mica and finely comminuted plant remains. This permits splitting into parallel slabs along bedding planes, which is common in many mines. In other places the medium-gray shale has a rather massive appearance and breaks into very large blocks almost as a massive limestone would.

Medium-gray shale commonly forms a smooth and relatively trouble-free roof in room-and-pillar mining. Aside from structural irregularities, main roof hazards are presented by slabbing and moisture slaking. Although slabbing is a minor problem, it is most pronounced where the rock is also well jointed or silty, and is best exhibited in the older areas of mines. Moisture slaking does not appear to be a serious problem in the mines studied; however, core samples of gray shales from many parts of the state, especially in the Troy area and the Danville area, exhibit a marked tendency to slake.

In mine B, particularly in study area 4, it was noted that the dark-gray shale generally pinches out over structural highs in the coal. The medium-gray shale is the immediate roof over these crests and shows more intense diagenetic deformation than anywhere else. Structures include large and closely spaced shear surfaces, and faults, some having thin clay filling and others having breccia between the shear planes. Prominent rolls, recumbent folds in shale and coal, are abundant in medium-gray shale and practically absent from dark-gray shale. Conspicuous splits in the upper part of the coal seam form local coal "riders." These conditions combine to produce rather weak roof over the structural highs. They also suggest that present-day structure in the mine still reflects trends of original topographic contours that existed during deposition of the roof strata.

Planar-bedded and cross-bedded siltstones and sandstones

Medium-gray shales, silty shales, laminated siltstones, and planar-bedded and cross-bedded siltstones and sandstones grade into one another. All transitions laterally and vertically exist within the Energy Shale, and may reach up through the position of younger members of the stratigraphic sequence, such as the Lawson Shale and Anvil Rock Sandstone. Siltstones or sandstones form the immediate roof in parts of many mines and may exceed ten feet (3 m) in thickness. Commonly both are light to medium gray, fairly firm, and marked by very fine, distinct, parallel laminations. Many bedding surfaces show a thin carbonaceous, and often micaceous, coating.

The planar-bedded sandstones are often interlaminated with dark-gray to black, carbonaceous shale partings, which vary from less than 1 mm to about

2.5 cm in thickness. The thinnest and darkest partings are composed of carbonaceous debris, fusain streaks, and bony coal, and have an abundance of mica on bedding surfaces. The thick partings usually consist of dark-gray, carbonaceous, rather argillaceous siltstone or fine-grained sandstone. The thick laminae are generally less well defined than the thin ones, but contained within are also thin, fissile zones, rich in organic matter. Cross-bedding, flaser-bedding, ripple marks and other synsedimentary structures are abundant. Large stringers or elongate lenses or wedges of coal, including coalified tree trunks (flat-lying) occur in some places. As in the medium-gray shale, rolls are common in this unit.

The position of the sandstones in the roof succession varies from directly overlying the coal in several places to overlying gray shales of variable thickness. Drill cores from many parts of the state show shales grading upward to siltstones to sandstone; however, in mine C, particularly in study area 6, the shale-sandstone contact is often uncomformable. The appearance is frequently that of small sandstone-filled channels that eroded into the shales beneath.

In many exposures, several separate channel-shaped sandstone bodies can be distinguished. They are superimposed upon each other, in many places with erosional contacts. Severe disturbances of soft-sediment deformation and intrusion of sand into the underlying coal have been encountered in connection with such sandstone bodies, especially in the "Quality Circle" area.

Bodies of sandstone, usually cross-bedded, that lie close to or upon the coal seam have definite linear trends. In mine C and other neighboring mines, the most notable trend is northwest-southeast, roughly parallel to the Walshville channel. Individual sandstone bodies locally strike in other directions.

Planar-bedded, thinly layered siltstones and sandstones are found throughout the "Quality Circle" area of southern Illinois, and in the roofs of mines in central Illinois and east-central Illinois, more than 150 miles away. They constitute a very treacherous roof material. Due to the weakness imparted by the carbonaceous and shaly partings, the sandstone roof is difficult to support and gives little warning of an impending roof fall. When failing, the sandstone and siltstone sheets fail at the anchor of the roof bolts, five to eight feet (1.5 to 2.4 m) above the top of the coal. The rock material reacts like a brittle material and tends to break almost straight up along the pillars. Such roof falls, once initiated, work their way up gradually and top out in notched or dome-shaped hollows often 10 to 35 feet (3 to 10 m) high. Other roof falls terminate at the base of a tabular or rippled sandstone sheet (figs. 19 and 20). When the roof falls cut upward into silty shales or shales, their crests often appear more V-shaped. The same failure pattern is shown in some falls of the Anvil Rock Sandstone from the black shale-limestone roof succession (fig. 21).

The sandstones occasionally contain water, which drains into mine openings both through roof bolt holes, and directly where a sandstone forms the immediate roof rock. This water seepage—noted to be especially troublesome in mine C—can be used as indication of sandstone roof. The water is salty, and may eventually cease dripping as the sandstones become drained, although in some areas roof wetness persists for extended periods. Pore pressure of water in the sandstones ought to be checked to see if it might influence the frequent



Figure 19. Roof fall in planar-bedded laminated siltstone of the Energy Shale Member. Many bedding surfaces are coated with coalified plant debris and mica. The diagonal (inclined 45°) dark stripes in the lower rock layers probably are water- or gas-escape structures. Location: east-central Illinois, mine D.



Figure 20. Roof fall in planar-bedded sandstone of the Energy Shale Member. Bedding surfaces are coated with mica and coalified plant fragments. No prominent joints are visible. Sandstone failed and broke almost straight up along the pillar rib. Location: "Quality Circle," near Walshville channel, mine C.

failure of shales below those sandstones, as observed in mine C, study area 6, or if the circulating water has weathered and altered the underlying shales and has reduced their strength.

Roof falls and occasional water problems are not the only difficulties associated with a sandstone and siltstone roof. The coal seam is also at an incline beneath sandstone or siltstone roof in many places. The combination of cross-bedding and siltstone partings in the coal seam, accompanied by coal "riders" in the roof rock and an inclined coal seam often not only results in an unstable roof, but can make mining difficult. Such areas can be identified on mine maps that show disruptions in the otherwise regular mining pattern.

Gray shale wedges
and lenses and transitions
into black shale-limestone roof rocks

Specific geologic conditions and
mine roof hazards are associated with

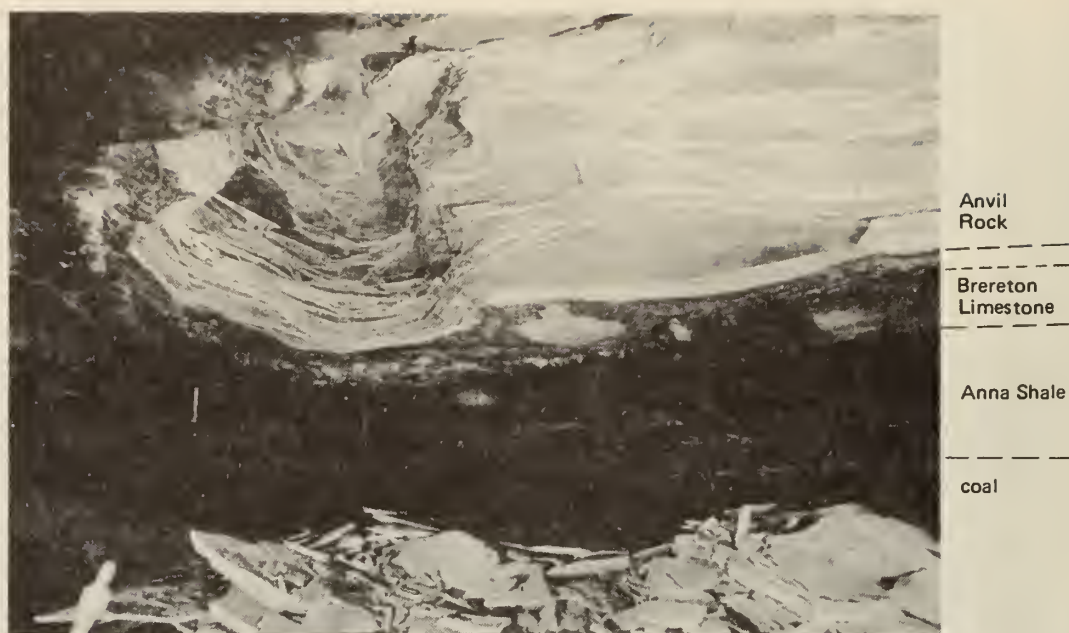
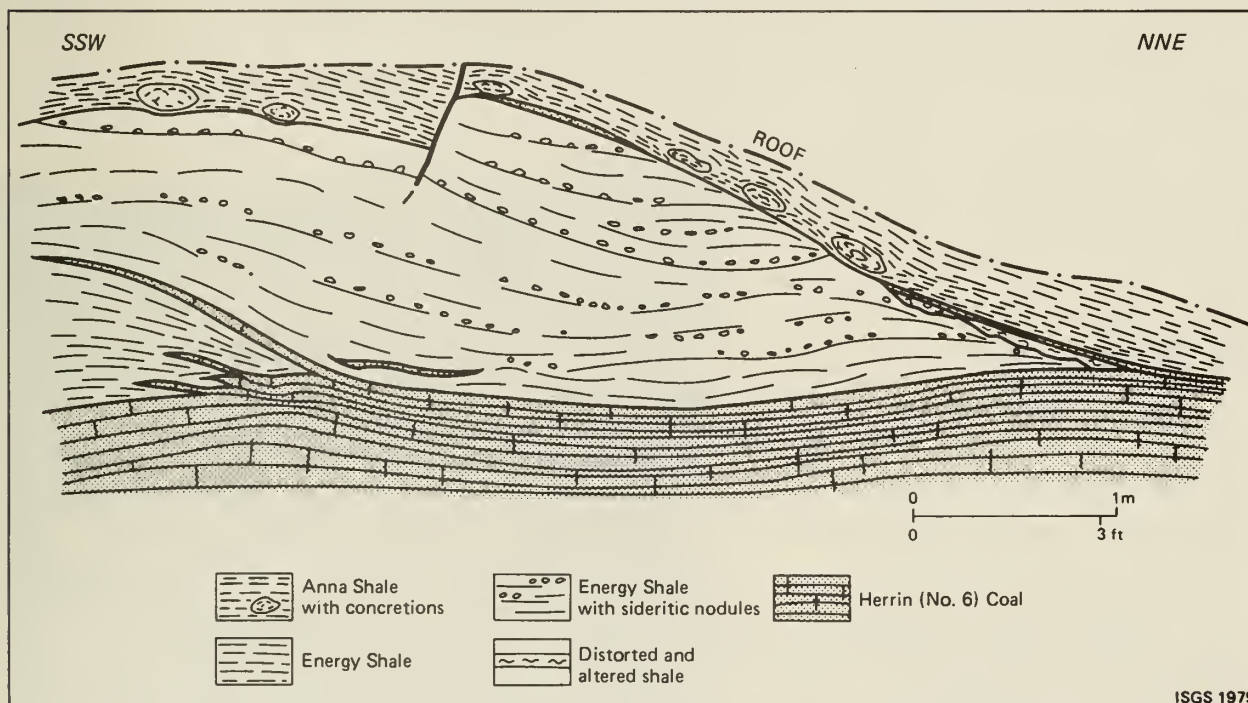


Figure 21. Roof fall in a sequence of Anvil Rock Sandstone (planar-bedded, light gray siltstone and sandstone), Brereton Limestone (gray, cloddy limestone with nodules and concretions), Anna Shale (weak, slightly mottled upper portion and well-bedded, well-jointed, fissile lower portion), and Herrin (No. 6) Coal. Roof fall extends up to a tabular, plant-debris-coated bedding surface of sandstone. Planar-bedded sandstones and siltstones of the Energy Shale often fail in the same manner. Location: Western Shelf, west-central Illinois, mine N.

the transitional areas between the gray shale and the black shale-limestone roof types. Although no transitional area was studied in detail, individual observations are reported, since in some Illinois mines Energy Shale transitions pose specific problems to roof control. Toward the rim of the "Quality Circle," the thickness of the Energy Shale decreases and the gray shales wedge out (fig. 22) or form local lenses and pods (fig. 23). Similar depositional features are known from strip and underground mines in southwestern Illinois on the Western Shelf and also in west-central Illinois. The immediate roof in many of the mines with gray shale transitions is commonly black shale-limestone roof, which usually remains stable after mining. But scattered throughout those mines are wedges and lenses or pods of gray shale from a few to a few tens of feet wide and as much as 20 feet (6 m) thick (figs. 22 and 23). Medium-gray shale lenses and wedges below black shale are usually easy to recognize. In some mines, however, the lowermost portions of the Energy Shale, the dark-gray shale, immediately underlies the black shales of the Anna Shale. Both are very dark gray to black shales, are well jointed, and tend to break along joints and form small slabs. They are not easily distinguishable, although, where present, their interface usually is a sharply separated surface. The contact between the gray shale and the overlying black shale-limestone roof generally is sharp and abrupt, providing easy separation of the two along their interface. The gray shale is usually softer and weaker than the black fissile shale, and wedges of gray shale are less capable of supporting their own weight. Roof failures are particularly frequent where the gray shale is about as thick as the length of the roof bolts and where anchors are set at or just below the interface of gray with black shale. "Bastard limestone," a medium- to dark-gray limestone containing abundant fossils, was encountered in a number of transitional roof areas in mines. The limestone has been found within the uppermost layers of the Herrin (No. 6) Coal and immediately above the coal or the gray



Figure 22. Thinning wedge of medium-gray shale (Energy Shale) above Herrin (No. 6) Coal and below black fissile shale (Anna Shale). The edge of the wedge is in the background of photo (left center). Although some roof bolts have been anchored in the Brereton Limestone ("cap rock" of the black shale-limestone roof) the gray shale and much of the well-jointed black fissile shale has fallen. The Energy Shale is unconformably overlain by the younger Anna Shale. Location: east of "Quality Circle," southern Illinois, mine I.



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Figure 23. Small lens of Energy Shale from transitional area of gray shale to black shale-limestone roof types. The configuration resembles slump structures and rolls described later in this chapter. Note also the coal stringers in and above the lens. Bedding of Energy Shale and Anna Shale appears to be unconformable. Small normal fault, probably resulting from differential compaction, is lubricated with coal. Location: edge of "Quality Circle," southern Illinois, mine H.

shale and immediately below the Anna Shale. Locally it appears also to be interfingering with the lowermost layers of Anna Shale.

Large accumulations of calcitic and pyritic coal balls have been encountered in the coal seam near the boundary between the gray shale and black shale roof. The entire height of one coal face was locally mineralized with coal-ball material so hard that entries could not be driven with continuous mining equipment.

Three characteristics observed in transitions from areas of gray shale to black shale-limestone roof are thought to be important indicators of environmental and ecological changes at the end of and shortly after deposition of coal-forming material:

1. Coal thickness appears to be greater under gray shale roof than under black shale-limestone roof.
2. "Bastard limestone" occurs in transitional areas more abundantly than under either other roof type.
3. Coal-ball density seems to be higher in transitional areas than elsewhere.

Observation of these characteristics after mining also indicates a change in roof conditions and roof stability.

The syngenetic wedges and lenses form individual geologic bodies and structural anomalies and are basic to initiation of soft-sediment deformation. Deformational structures such as subsurface slumping, soft-sediment intrusions, folds, and faults are abundant and result from differential adjustment of the various bodies during compaction and diagenesis and in places from lateral and vertical movement caused by differential basin subsidence.

STRUCTURES AND DEFORMATIONAL FEATURES OF THE GRAY SHALE ROOF TYPES

Roof falls are commonly caused by rock anisotropies and structural anomalies in the roof rock. The origin of such features may date back to the time of deposition or to later deformation. Some may even be caused by mining activity. We have classified features that influence roof stability in the Herrin (No. 6) Coal according to their geologic genesis. Although such a genetic classification based on time of formation (syngenetic, diagenetic, or epigenetic) is difficult to apply in a practical way, it may be a suitable approach for geologic analysis of the structural features that influence roof stability. Structural development and tectogenesis of a geologic body is a continuous process that begins with the sedimentary environment before and during sedimentation and continues through diagenesis and also later deformation.

Depositional structures (Syngenetic structural features)

Bedding planes, laminations. Syngenetic structural features include all structures that developed during deposition and during the early stage of diagenesis. Most of these structural features are associated with bedding, the fundamental property of sediments. Lithologic changes in sediments invariably bring about horizontal or subhorizontal bed separation (bedding planes), internal bed irregularities, and deformation structures, which produce zones of weakness in the sediment.

In planar bedding, we include laminated, massive, graded, and lenticular bedding, and cross-bedding. Massive beds of limestone or sandstone are rarely seen in roof falls and will normally fail only if other structural weaknesses are present. Even gray shales seem to form a stable roof where they are massive or display few or poorly developed bedding planes. Laminated, thin-bedded sediments, on the other hand, are subject to failure, particularly where bedding planes are covered with a thin film of plant fragments (fig. 24). The occurrence of these roof falls seems to be related primarily to the mechanical properties of the sandstone and intercalated plant debris coating. The well-bedded silty shales and their interbedded siltstones and fine-grained sandstones are weak and brittle.

Curved bedding includes such sedimentary structures as flaser, spatulate, rippled, and crinkled bedding. Some types of cross-bedding and lenticular bedding may belong more properly under this category, but normally these types will be referred to as semiplanar bedding phenomena. Of the bedding types listed above, only flaser bedding occurs both in the Energy and the Lawson Shales. Underneath or adjacent to such depositional irregularities, roof problems are expected. Few such irregularities were observed during this study. They are characteristic of channel facies and are not common in the immediate roof of coal seams.

Irregularities on bedding surfaces include linear features such as drag marks and current marks, small-scale channels, scours, and other striations of movement. Drag and current marks can frequently be observed, but are too small to interfere seriously with roof stability. Locally, however, scour bedding and small sand channels have some negative influence on roof stability. Mud cracks, dessication cracks, flakes and curls, mud pebbles, worm boreholes, and other indications of bioturbation, and erosional and weathering features should all be placed in this category. None of them seem to be of major importance to roof stability of the Herrin (No. 6) Coal.

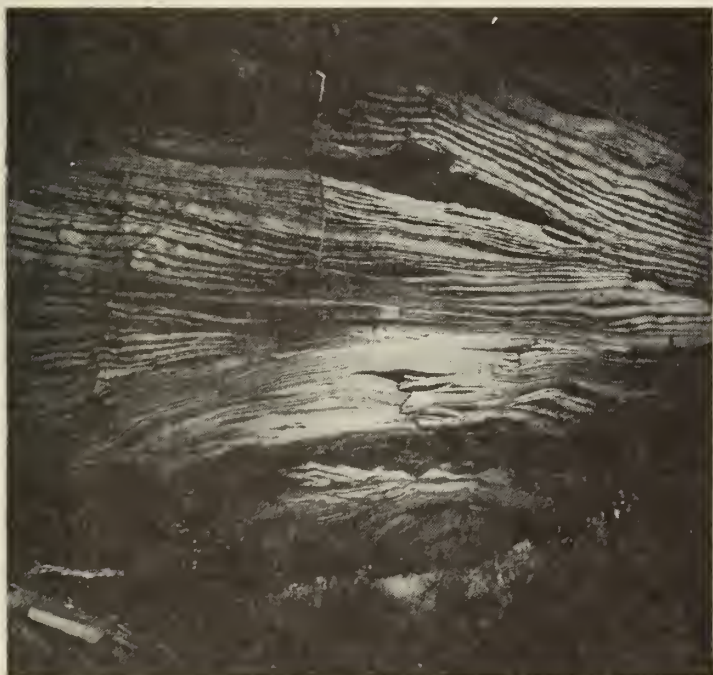


Figure 24. Planar-bedded sandstone and bedding-plane anomalies in the vicinity of the Walshville channel. Main weaknesses contributing to the roof instability are the thin bedding and lamination of the sandstone and a film of coalified plant debris coating the bedding surfaces. Note the thinning and wedging of some sandstone layers (center and lower left side of photo) and the disturbed bedding planes in the roll above the coal (lower center of photo), which is interpreted as a soft-sediment deformation structure. Location: mine C, "Quality Circle," southern Illinois.

Split coal. Split coal contains bands or partings of clastic sediments. It is commonly found in areas adjacent to the Walshville channel. In some areas wedges of gray shale or silty shale interfinger with the coal without any noticeable reduction in coal thickness. In other areas, particularly where siltstones or sandstones interfinger with the seam, coal thickness is decreased, and previously deposited coal appears to be missing (these are called wash-outs). Erosion plus interfingering are indicative of coexistence of the coal-forming swamp with erosion and deposition of sediment in channel systems.

Most anomalies (slips, slumps, and rolls) that cause roof problems in areas of interfingering between coal and clastic sediments have formed subsequent to sedimentation during compaction and diagenesis. Yet, the irregular shape and the abrupt change in thickness and lithology of immediate roof strata (characteristic for areas of split coal) have established preconditions for the development of younger deformational features. One type of structure has developed simultaneously with the coal splitting and contributes significantly to roof instability, however: thin stringers and bands of coal up to a few inches thick ride on top of small gray-shale lenses and wedges and interfinger with the topmost portion of the seam. Rarely do those gray-shale lenses and wedges occur directly above the seam without "riders." Coal "riders" in connection with rolls at the top of the coal seam may be somewhat related to splits, but they are soft-sediment deformational features, syngenetic to diagenetic rather than syngedimentary.

Widespread split coal has also been found in a number of mines, including mines C and G, and has been recorded from drill holes and in mine notes. Splits as observed at mine C are thin (only a few inches) and lie near the top of the seam. The most prominent split consisted of 1 to 2 inches (2 to 5 cm) of sandstone about 6 inches (15 cm) from the top of the coal, persisting for more than 100 feet (>30 m). Most splits at mine C consisted of little more than thin shale partings in the upper part of the seam. Several drill holes to the west of the present mine workings, however, penetrated coal that had shale splits a foot or more thick (>30 cm).

The split observed at mine G was much more spectacular (fig. 25). The upper 18 to 20 inches (45 to 50 cm) of coal curved upward, while the lower main bench dipped sharply downward. The shale parting increased from a feather edge to about eight feet (2.4 m) thick within the length of two crosscuts (about 150 feet [45 m]). Then the upper coal bench disappeared in the roof. A drill hole more than a mile ahead of the face showed what appeared to be the same split, about 30 feet (9 m) thick. In the other direction, the split narrowed to a parting, which is a persistent layer through the entire mine, about 18 to 20 inches (45 to 50 cm) below the top of the coal.

In some drill holes in southern Illinois, the split Herrin (No. 6) Coal occupies more than 50 feet (15 m) of section. An unusual case occurs in a strip mine in Jackson County, where the Herrin (No. 6) Coal is divided into as many as four benches of minable thickness separated by up to a total of 100 feet (30 m) of gray shale.

Sometimes splits in the coal can be indicated by a coarsening of the roof rock and by an increase in the number and thickness of shale partings in the coal. During mining these partings could be found to thicken into true splits. The thickening may be either abrupt, as at mine G, or gradual, as at mine C.

Split coals present obvious difficulties in mining, as they require either mining along a thinner bench or handling large amounts of rock. A split near the top of the coal is also a roof hazard. The upper bench of coal provides a layer of weakness along which shale partings break and fall.

Concretions. Concretions are formed by precipitation of mineral matter in the pores of a sediment around some kind of nucleus (e.g., animal or plant remains). They are normally roughly spherical and seldom oblate or irregular (fig. 26). Concretions are abundant in the Anna Shale Member above Herrin (No. 6) Coal (fig. 67). Concretions in the Energy Shale are mostly small and rare. Occasionally, calcareous or pyritic concretions of considerable size are found in the medium-gray shale facies (fig. 26). They are not a significant roof hazard in gray shale roof. The only noteworthy concentration of such concretions was found in the northwestern portion of study area 4 in mine B.

Tree stumps. Tree stumps, on the other hand, are in places a local hazard in gray shale roof areas. Tree stumps also have been mapped in the dark-gray shale strata of study areas 4 and 5 in mine B. In places, tree stumps are clustered in large numbers; others are scattered over wide areas. These tree stumps, which may be a foot or more in diameter, were embedded in a more or less upright position in the muds that became dark-gray shale. They were either in situ or possibly floating stems which sank down with the heavy (stump) end first. The stumps decomposed and were hollow at the end. The bark and some wood became coalified and now is found as a round or oval thin stringer of coal in the immediate roof. The hollow trees were filled with the same sediment in which they were deposited. The coalified bark separates the rocks inside the stump from rocks outside the stump. These tree stumps, among miners known as "kettle bottoms," are a hazard to men in underground mines because the central plug of rock may easily separate from the coalified rind and fall out of the roof.

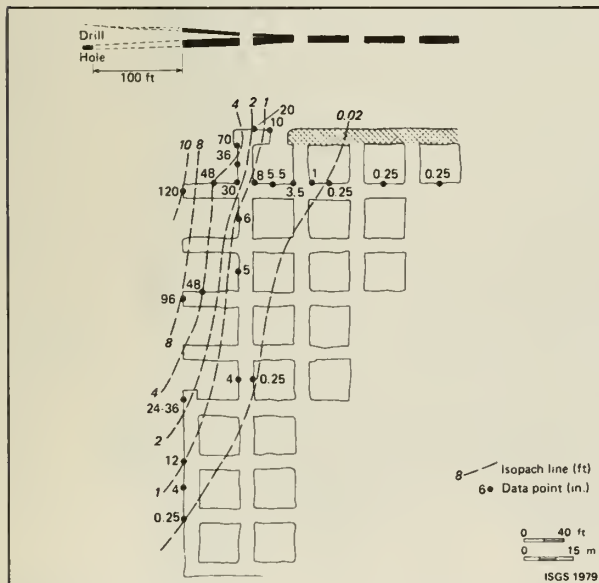


Figure 25. Split coal; isopachous map of shale in a split in the Herrin (No. 6) Coal in mine G, east-central Illinois. Split consists of fine medium-gray shale near top of coal seam.

Other local irregularities that may be dangerous to miners are (1) thin synsedimentary coal "riders," (2) lenticular deposits of particular sediments like the accumulation of fossils in "bastard limestone" lenses, (3) load casts and similar structures of coarse-grained clastic sediments in otherwise fine- to medium-grained strata (fig. 27), (4) casts of bioturbation, (5) water or gas escape casts (fig. 19), and (6) small "explosion" structures, which form from release of excess pore pressure (fig. 28).

Rolls, faults and shear bodies (Diagenetic structural features)

Loosely packed, water-saturated sediments are transformed into solid rock during diagenesis, mostly by compaction under the load of younger sediments, and by various chemical processes



Figure 26. Concretions in gray shale roof usually are not as spherical as those in the Anna Shale. These concretions in combination with planar-bedded silty shales and siltstones are a hazard to miners. Note the thin gray shale of the Energy Shale underneath black Anna Shale, above the Herrin (No. 6) Coal. Location: mine E, southwestern Illinois.



Figure 27. Synsedimentary small slump and load structures of coarse-grained clastic sediments in otherwise fine- to medium-grained argillaceous limestone. In places, they not only cause excessive wear on mining tools but are prone to fall out of the roof. Scale (at right side): 15 cm. Location: mine H, "Quality Circle," southern Illinois.

within the sediments, in particular, cementation. The formation of concretions, syneresis cracks, and various small compactional structures, which begins syn-genetically, also continues during this phase of rock formation. Many changes in texture and structure of sediments take place during compaction, and previously formed and deformed structures may undergo further deformation. It is thought that most of the rolls and associated features—slips, minor faults, major shear planes, and shear bodies—are formed during this phase of diagenesis.

Rolls and associated features. To a coal miner, a "roll" is any protrusion of the roof material into the coal seam. Rolls are abundant in all of the studied mines that have gray shale roof. Rolls are complex soft-sediment deformation structures that severely influence roof stability. They range from a few inches wide and an inch high to a hundred feet (30 m) wide and about seven feet (2 m) high. Although they are variable in size, appearance, and distribution, rolls have many features in common. Areally and in cross section, a typical roll (fig. 29) is shaped roughly like a football. One edge, the toe, of the structure generally is marked by a coal "rider" that curves upward into the roof and splays out into a series of feather edges. The toe is blunt. Larger rolls generally have thicker "riders"; three-to-five-inch (7-to-12-cm) thicknesses are common, and a two-foot (60-cm) thickness is exceptional. The cleats in the "rider" coal are normally perpendicular to the curved bedding surfaces. The other end, the "tail" of the roll is wedge-shaped, less blunt than the toe, and seldom has a "rider." The tail "rider," where present, is generally smaller and does not extend as far into the roof as the toe "rider." If no tail "rider" is present, the tail of the roll may be difficult to locate. The material of the roll enclosed by the "riders" is generally the same as or very similar to the immediate roof, except in transitional areas, where gray shale rolls occur under black shale-limestone roof. In many small rolls (less

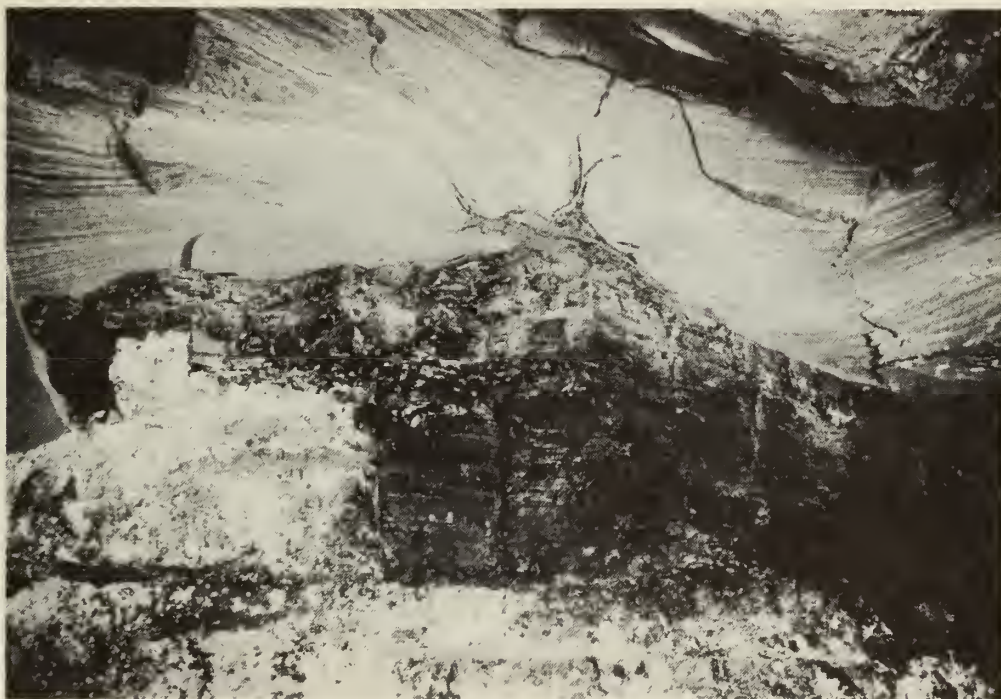


Figure 28. Explosion structure of coal into laminated, normally planar-bedded siltstone and silty shales. These structures, which show deformed coal layers and torn-up and tilted roof rock, were formed as a result of sudden release of excess pore pressure. Scale (on top of coal, left side of picture): 5 cm. Location: mine D, east-central Illinois.

than two feet thick) the bedding in the roof normally is concentric with the "rider," and the bedding within the roll is concentric with the "rider" above and the main coal seam below. Layering is generally horizontal in the center.

Large rolls (more than two feet thick) exhibit all the features of smaller ones and contain additional complexities. In large rolls, the coal "riders" may attain thickness of one to two feet (30 to 60 cm), and the coal seam thickness may be reduced by three to four feet (90 to 120 cm). The coal seam may dip under large rolls, although the entire configuration is seldom visible because the bottom of the coal in many places is not mined and remains part of the floor. The bedding within the roll almost always is irregular or disturbed by soft-sediment deformation and faulting. In many places the roof above the roll also is deformed; however, bedding cannot be recognized in all rolls. Effects of deformation and lateral mass-movement range from simple folds to highly contorted recumbent or overturned folds (figs. 30 and 31). Deformation, which includes recumbent folding and subhorizontal shearing, is generally most intense at the toe of the roll (fig. 32).

Rolls are abundant in the medium-gray shale and siltstones and sandstones of the Energy Shale. Rolls in dark-gray shale are rare and usually small, at most a few feet wide and a few inches thick. Rolls are almost unknown in mines with only black shale-limestone roof. The features most similar to a roll, observed under black shale-limestone roof in mine A, are "washouts." Under limestone roof, downward protrusions, known as limestone "bosses," are sometimes found, but these lack "riders" and other features of rolls.

In mine B, rolls occur almost exclusively in medium-gray shale roof (figs. 33 and 34) and are almost totally absent in dark-gray shale roof. The maps also

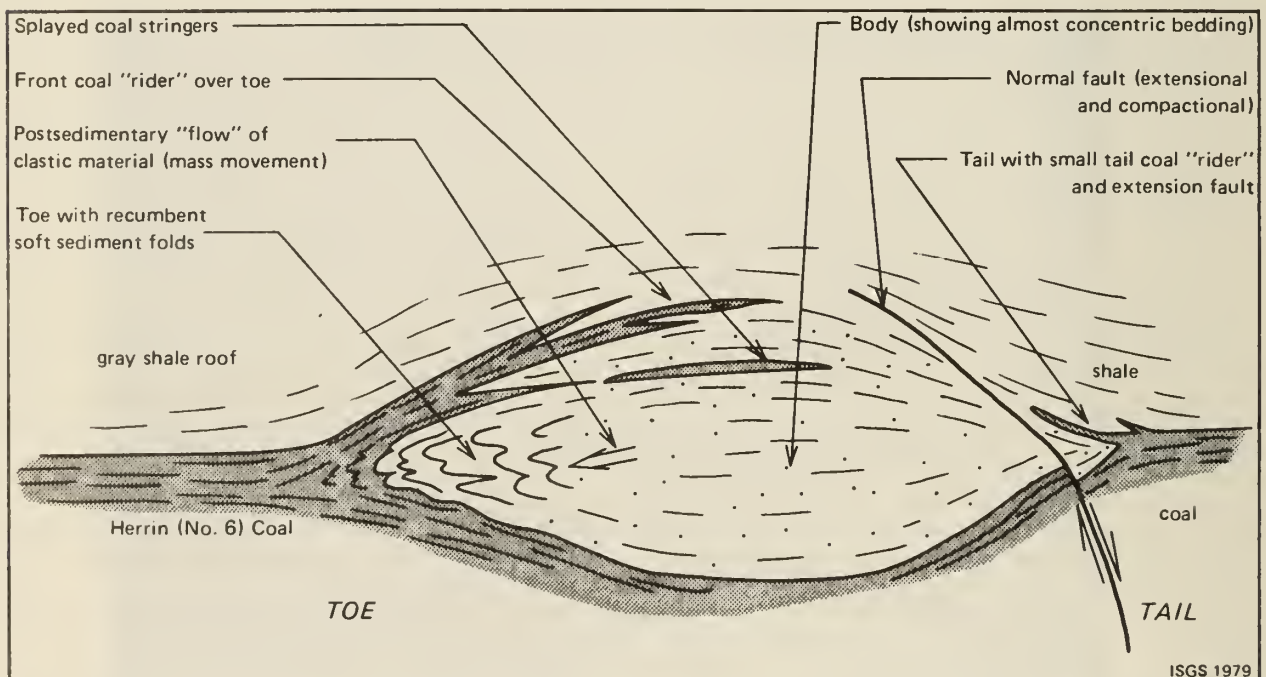


Figure 29. Sketch of typical roll (soft-sediment protrusion of clastic materials into surrounding sediments—coal, shales, siltstones, and sandstones).

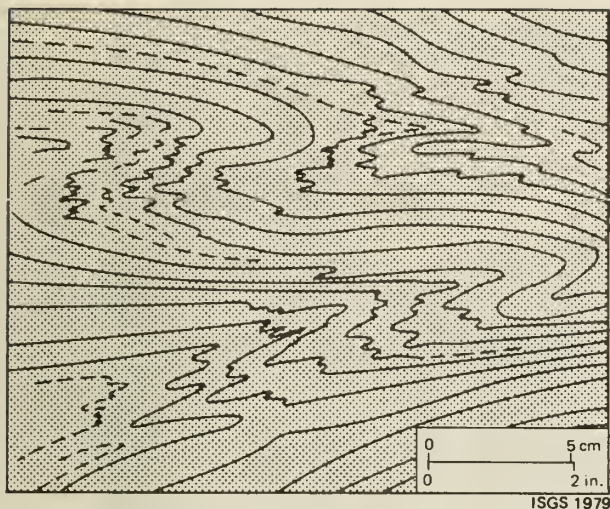


Figure 30. Small irregular (disharmonic) recumbent folds (soft-sediment deformation) in Herrin (No. 6) Coal, often found in association with gray shale rolls in the coal, but also found independently in coal. Location: "Quality Circle," southern Illinois, mine B.

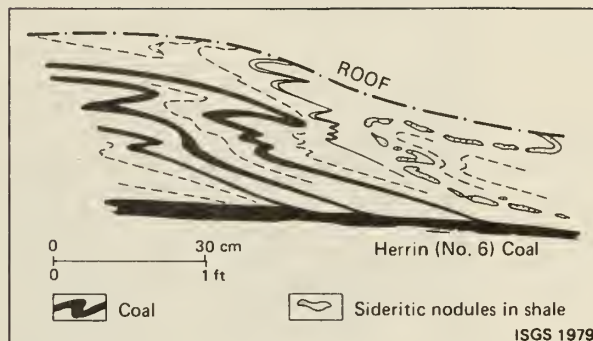


Figure 31. Soft-sediment folds in a roll. The folds signify injection or squeezing of Energy Shale into and above Herrin (No. 6) Coal. Location: "Quality Circle," southern Illinois, mine O.

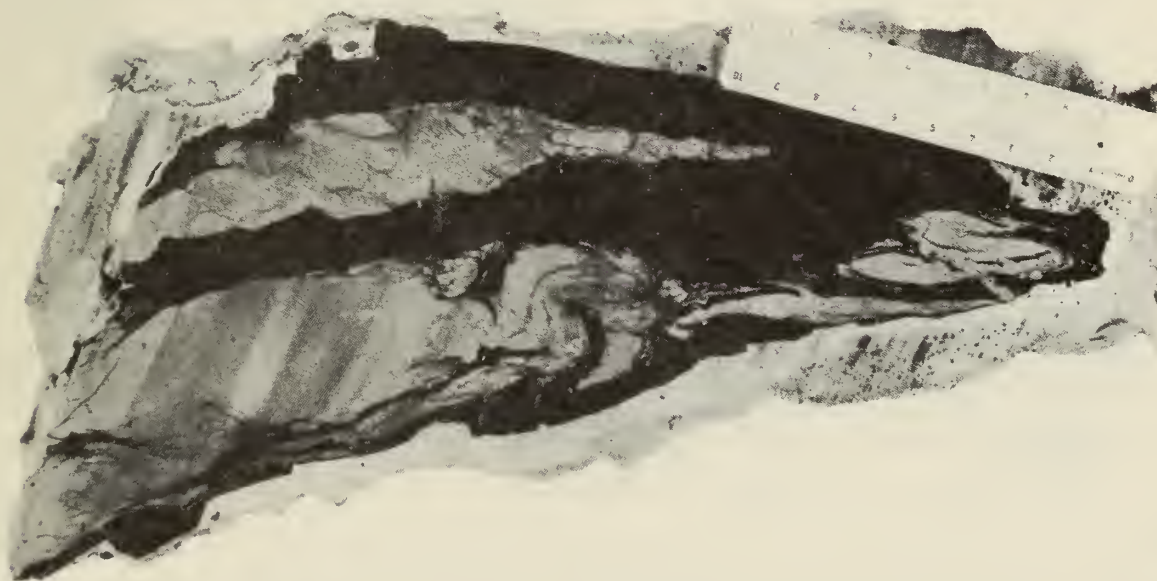


Figure 32. Specimen of small roll having pointed toe of recumbent folds and more or less horizontal shear planes. Silty shale of the Energy Shale intruded into Herrin (No. 6) Coal. Scale: 10 cm.



Figure 33. Roll of medium-gray shale of the Energy Shale intruded into top layers of Herrin (No. 6) Coal. Toe (at the left) splits folded coal strata into several stringers. Tail has been truncated by compactional normal fault (at the right). The rod is about 4 feet (1.2 m) long. Location: "Quality Circle."

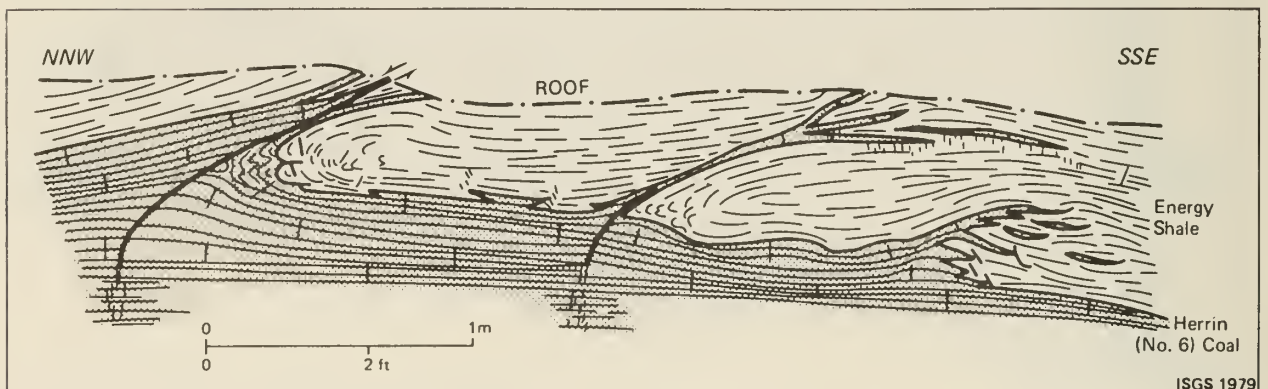


Figure 34. Soft-sediment deformation of Energy Shale protruding from the roof and producing rolls. Note the riding coal stringers that have been split off from the seam, the folded toes of the rolls and the coal in front of it, and the low-angle normal faults that steepen downward and dissipate into the coal as "goat beard." Location: "Quality Circle," southern Illinois, mine B.

show that rolls display a marked tendency to strike parallel to the lithologic border of dark shale and gray shale. Another example has been found in mine C (fig. 35). The situation is much like that at mine A, where faults and clay dikes also follow lithologic boundaries. Another notable feature at mine B, especially in study area 4, as previously noted, is that medium-gray shale and rolls generally seem to be clustered at structural highs or slopes in the coal. The relationship is so persistent that gray shale and rolls can be expected where a hill occurs in the coal. Conspicuous rolls occur in mine C in association with the siltstones and sandstones, and smaller, less abundant rolls occur in the same mine in areas with gray shales as immediate roof (figs. 35 and 37). The largest rolls found during this study were in siltstones and sandstones. The deformational features of rolls, especially contortion in the main roll body, are evident in the dark and light layers of planar-bedded sandstone (figs. 37 to 40).

The largest rolls are in study area 7 of mine C, where sandstone forms the immediate roof (fig. 38) and the coal undulates strongly and thickens as much as 12 feet (3.6 m) over the crests of hills. Many of the rolls are grouped together in a northwest-trending belt. The belt is 50 to 200 feet (15 to 60 m) wide and has been traced directly for about 1,000 feet (300 m) across three panels. The zone of sandstone roof in study area 6 of mine C is on strike with this belt, as is a zone of severe rolls in an abandoned portion of the neighboring mine O to the southeast.

An exceptionally large roll, termed a "mega-roll," was mapped in the southern part of study area 7. It is up to 100 feet (30 m) wide and several hundred

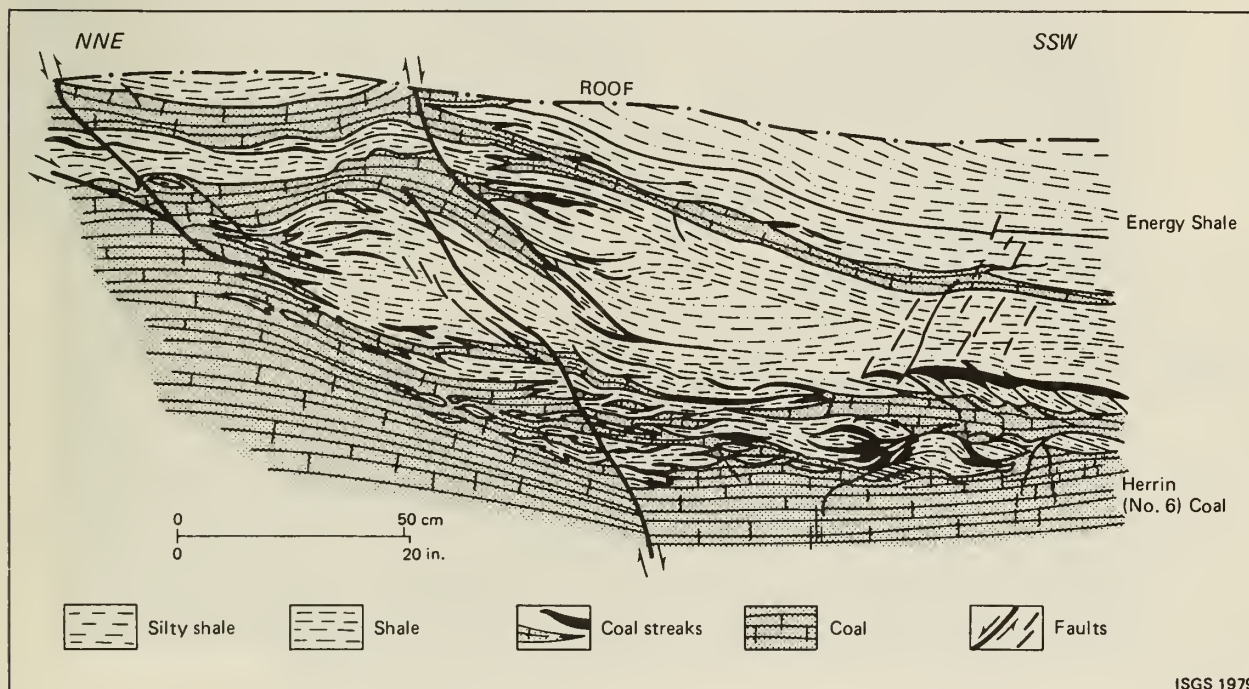


Figure 35. Soft-sediment protrusion and deformation of Energy Shale material into the top strata of Herrin (No. 6) Coal. This complex roll is possibly penecontemporaneous to the deposition of sediments in the Walshville channel. The younger small normal faults and shear planes probably result from differential compaction. Location: "Quality Circle," southern Illinois, mine C.

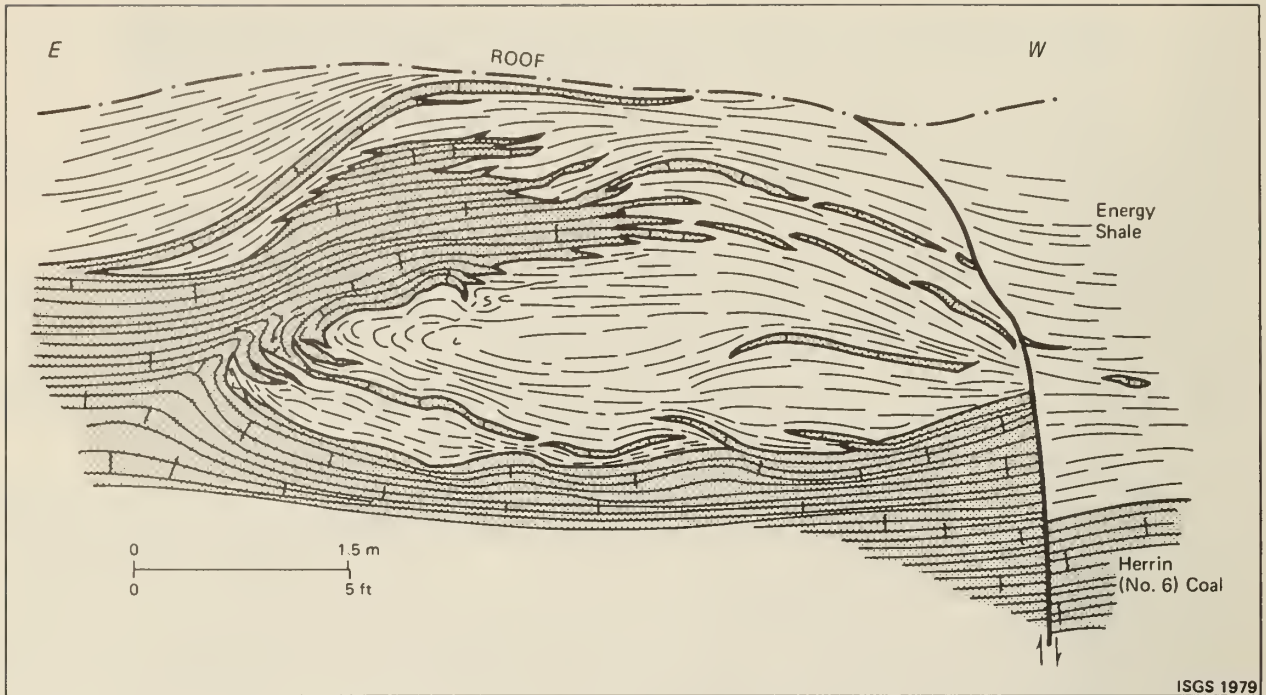


Figure 36. Soft-sediment protrusion of Energy Shale from the roof into the top strata of Herrin (No. 6) Coal (roll). The toe of the large roll is folded, and the coal stringers, split off the main seam, have been deformed to a fishtail structure because of differential compaction, which also caused the normal fault at the tail of the roll. Location: edge of "Quality Circle," southern Illinois, mine M.



Figure 37. Large roll: Protrusion of clastic material of the Energy Shale, mainly siltstone and sandstone, from the roof into top of the Herrin (No. 6) Coal, probably penecontemporaneous to sedimentation in the Walshville channel. Rolls of this type are abundant in the "Quality Circle" area of mines C and O in southern Illinois and also have been recognized in east-central Illinois in mines D and G. Note the downward dipping of the bedding and the split of the coal strata, forming coal riders and the irregular pattern of shear planes and small normal faults, which result from differential compaction. The siltstone laminations and layers are unconformable in the main body of the roll.

Figure 38.

Roll in planar-bedded siltstone and sandstone of the Energy Shale Member. Near the toe of the roll (arrow), recumbent soft-sediment folds and low-angle shear planes are visible. These features suggest that the silt and sand filling the roll intruded from right to left between the layers of peat. (Note the coal "rider" originating at the toe and extending almost entirely over the roll.) The large low-angle slips at the tail of the rolls may have formed later by differential compaction.

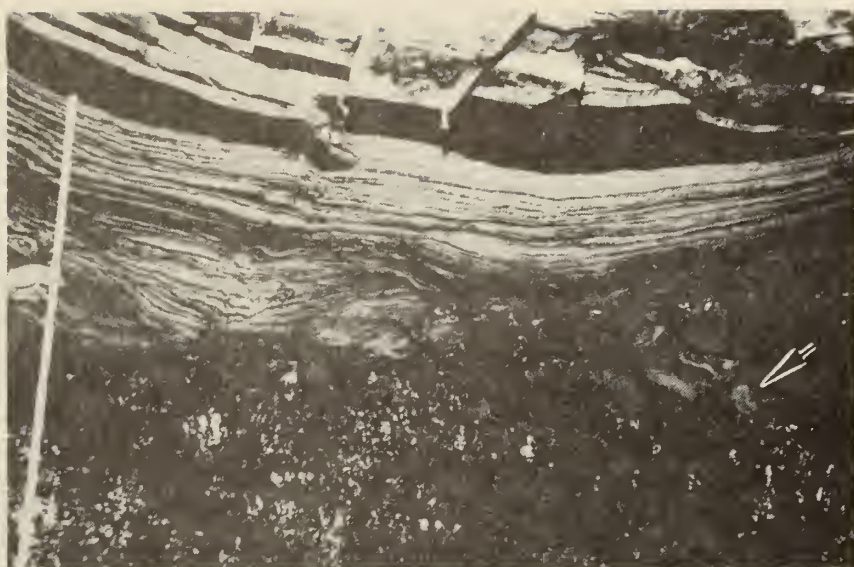


Figure 39. Detail of figure 38.

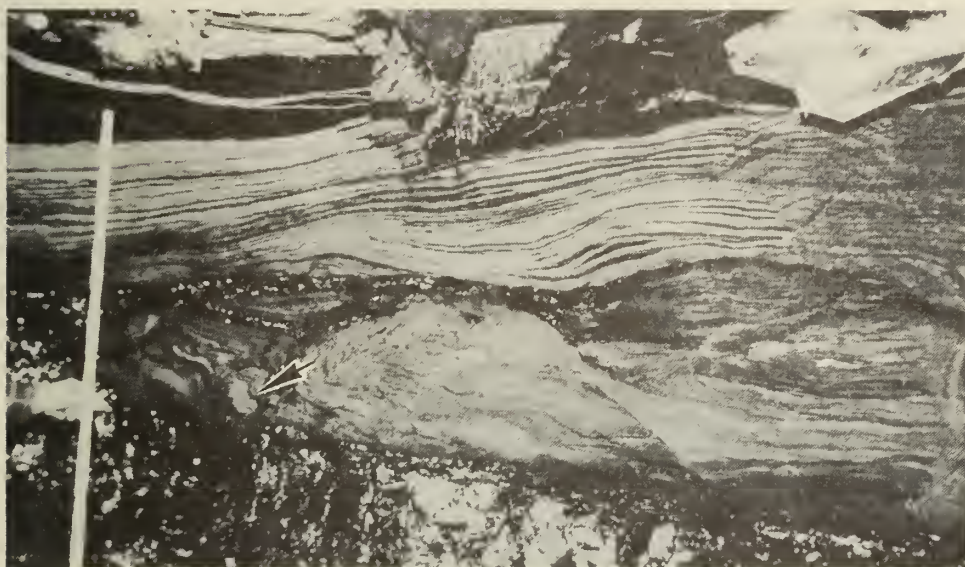
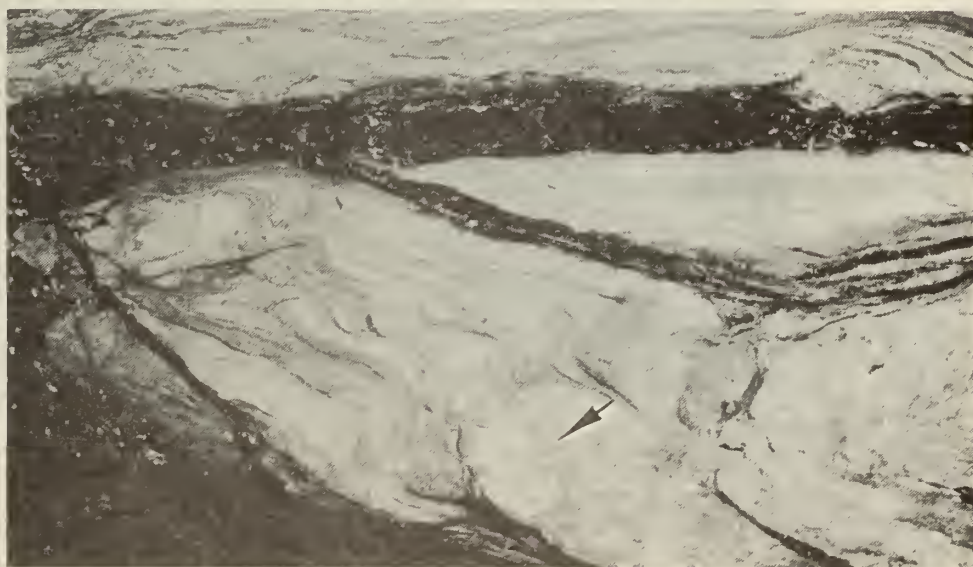


Figure 40. Detail of figure 39.



feet (several tens of meters) long, and is somewhat irregular in outline. The coal seam is warped downward as much as 12 feet (3.5 m) under the roll. Although the coal is continuous under the roll, the inclination is too steep for mining machines to negotiate. The toe of the mega-roll is directed toward the north and has a coal "rider" nearly two feet (60 cm) thick. The coal-roll interface dips sharply downward toward the trough of the roll, then rises symmetrically toward a well-defined tail on the south. Near both toe and tail, the sandstone laminae show intense recumbent folding, and streaks of coal appear overturned as "riders" above the roll. Approaching the center roll body from either side, recumbent folds give way to extensional microfaulting. The sandstone-siltstone beds in the center of the roll, at its low point, are parallel-laminated and neither folded nor faulted, yet they appear to be "stretched." Toward the west the roll becomes strongly asymmetrical and gradually changes its outside appearance.

The entire study area 7 of mine C has an unstable roof and numerous large falls and poor mine conditions; however, mapping of rolls and associated features demonstrated that zones of rolls, even mega-rolls, can be penetrated and normal mining continued beyond. In study area 6, we found water-bearing, planar-bedded sandstone roof and undulating coal, but no major rolls. Minor splaying of top strata of coal and in places irregular coal-roof contacts are interpreted to be the only indications of early postsedimentary lateral mass movements.

Rolls also occur in transitional areas of gray-shale wedges and lenses underneath black shale-limestone roof. Some small rolls underlying black shale-limestone roof are formed by gray shale resembling Energy Shale. In most cases the gray shale occurs only within the body of the roll, which in places is entirely below the level of the top of the coal (fig. 41). A thin layer, or

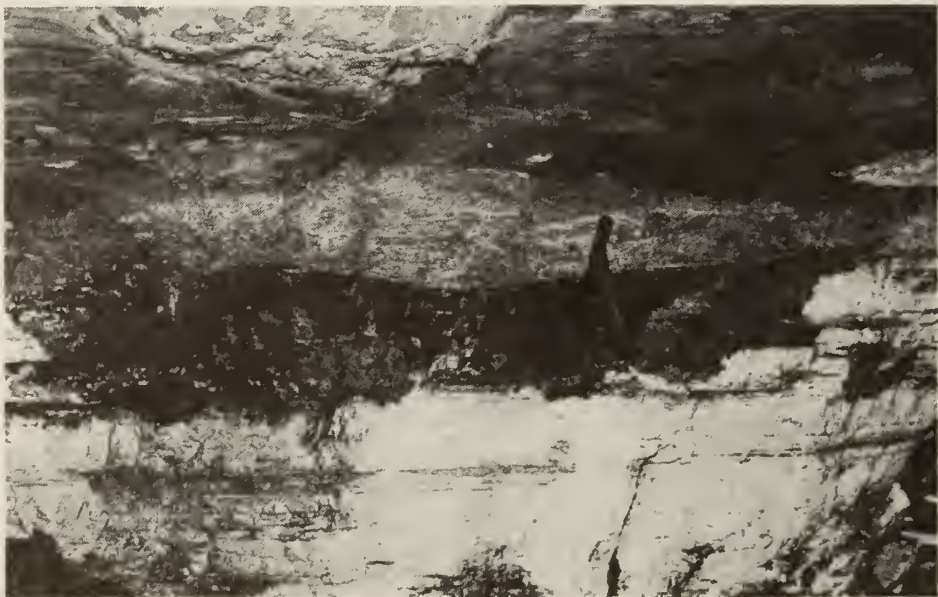


Figure 41. Small pod of medium-gray shale (of the Energy Shale) is between the Herrin (No. 6) Coal and a black fissile shale (of the Anna Shale Member). These gray-shale bodies tend to be deformed to rolls and are frequently interpreted as rolls. Lateral mass movement is indicated by low-angle shear surfaces (slips), extension fractures, and "goat beards" in the coal; see left side of gray-shale pod. Location: southern Illinois, mine I.

"rider," of coal may intervene between the roll and the black shale above. Generally the black shale is even-bedded and undisturbed; however, in a number of places it has been found to unconformably overlie the gray shale (fig. 23).

Rolls are a significant cause of roof instability in all the mines studied. The chief source of danger lies in their coal "riders," which form a surface of serious weakness and separation in the roof, and in the associated extensional shear planes. The folding and unruptured distortion of bedding within the rolls probably is of minor influence on roof stability. When mining through "roll country," the use of many long bolts anchored well above coal "riders" appears to be essential. Under large rolls, additional supports such as cribs and timbers are required in many cases. The trends of rolls or sets of rolls should be recognized and mapped and then evaluated on a case-by-case basis. According to most observations, rolls tend to follow lithologic boundaries. Major sets of large rolls also may follow predictable courses for long distances, which may allow adaptation of the mining plan.

Minor faults (slips). Minor faults (slips) have long been recognized by miners as causes of roof instability. They are found in practically all coal mines having gray-shale roof. Compared to facies effects, rolls, and major shear planes, the minor faults at mines B, C, D, and G have only local but relatively little effect on overall roof stability. Most minor faults studied are of a specific type that will be described in more detail later. Very small slips occur in every facies of the Energy Shale. Most of these can be traced for only a few feet along curving or irregular courses, and displace no more than a few inches. Many minor faults, some traceable for a hundred feet (30 m) or more, are found in connection with rolls and present a more serious danger. Most of these cut the roof and at least the upper part of the coal, and show displacements of as much as about a foot (figs. 33 and 35).

The origin of a minor fault in gray shale roof may not always be obvious, but generally can be attributed either to loading and differential compaction or to gravitational sliding of the deposits above the coal. Unlike the clay-dike faults, which generally steepen downward and produce extension fractures in the coal (p. 85), minor faults of the gray shale tend to flatten out downward and often become indistinguishable in the bedding of the immediate roof shales.

Our maps, with their limited size and scale, show distribution, frequency, and orientation of minor faults apparently to be random. Minor faults are primarily concentrated in areas where the gray shale also undergoes rapid changes of thickness within short distances and where rapid facies changes are common. This is particularly the case in the transitional areas, where the gray shale wedges out or is absent, and in areas of split coal, near the Walshville channel.

Commonly associated with minor low-angle faults or with gray-shale wedges and rolls are small antithetic high-angle shear planes. They penetrate only a few beds and pinch out abruptly in strike and dip direction (fig. 42).

Some faults not associated with rolls can be traced for some distance, and they penetrate the roof, the coal, and, in some cases, the floor. These bear most of the marks of clay-dike faults, but differ from the typical faults of mine A in that they lack clay filling and generally are steeper, 60° to 75° being common, than those in mine A (fig. 43). Such high-angle faults of little displacement are especially common in mine C, study area 7, and in mine E. A few faults at mine B contain thin clay filling and are identical to faults at mine A. Small clay dikes (fig. 44) are rare.

Dangerous faults we encountered are large moderately low to low-angle shear planes occurring in thick gray shale at mine B. These slips may transect ten feet or more of roof strata but generally do not affect the coal. Large falls occurred along faults of this type at C-2 in study area 5 and CD-34 in area 4. These faults appear to be related more closely to the major shear surfaces as described below than to clay-dike faults.

Roof falls related to minor faults commonly occur prior to bolting, many times with as much as 3 feet (0.9 m) of roof rock dropping out from underneath a fault plane (fig. 45). This type of roof fall occurs immediately upon removal of the coal, although in a few instances falls of this kind result because the time interval between coal removal and roof bolting is too long.

Major shear surfaces and shear bodies. Numerous examples of major shear surfaces, which are low-angle, subparallel, or even parallel to bedding, were found in the gray shale type of roof. Shear surfaces parallel to bedding

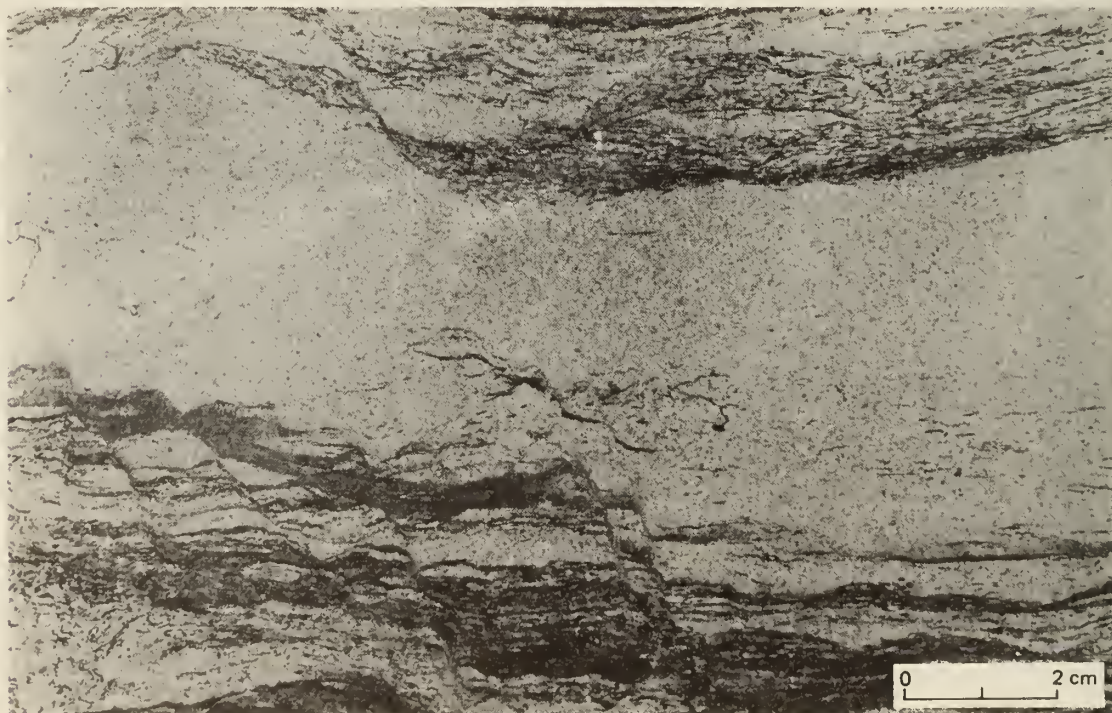


Figure 42. Small-scale high-angle normal faults, often associated with rolls, gray-shale wedges or antithetic-extension shear planes with low-angle slips. These faults are considered by many geologists to be caused by differential compaction. Here the small faults were laterally stretching the width of a small roll within top layers of the coal.

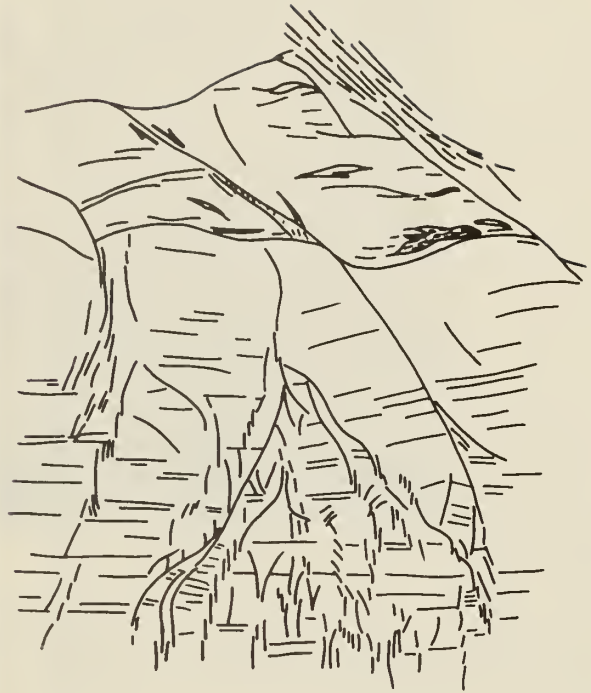


Figure 43. Gray shale roll sheared into several blocks. Shear plane pattern of high-angle synthetic and antithetic faults in Herrin (No. 6) Coal, which steepen downward, resembles clay-dike faults as found under black shale-limestone roof. Location: southern Illinois, "Quality Circle," mine C.



Figure 44. Small clay dike associated with even smaller clay-dike faults under gray shale roof. Clay dikes under gray shale roof are rare. False drag of the bedding is found in the immediate vicinity of the faults. Location: southern Illinois, "Quality Circle," mine B.

often can be recognized only by the presence along the bedding planes of parallel striations of slickensides, which result from movement between layers of rock or coal. This type of shear plane is a roof hazard because the slab of rock below the shear is essentially loose from the rock above (fig. 45). The weight of such a slab may exceed the capacity of mechanical roof bolt anchors. Where the roof is bolted every four feet (four-foot centers), each vertical foot of thickness of rock loosened along a shear plane loads about 2,500 pounds on each bolt. As anchorage capacity for expansion shells in gray shale ranges from 6,000 to 18,000 pounds, a slab of rock more than 2½ feet thick may be enough to pull out the bolts, particularly if the roof is also fractured vertically.

In mine C, study area 7, shear planes parallel to bedding occur in the coal and along the coal-roof contact in areas where the layers are tilted or folded. Some shear planes displace high-angle faults; others can be traced to steeper inclined faults and appear to be offset by them (fig. 46); evidently shearing and folding affected each other. Shear planes occur in both dark-gray and medium-gray shale facies in mine B. They do not appear to be limited to areas of soft-sediment folding. Most of the shear planes occur in about the bottom foot of the roof, and no large falls can be attributed to them; however, severe roof problems in mine B, study area 5, were caused by an assemblage of shear surfaces in a totally deformed rock unit, which we call the "shear body." The shear body consists of pervasively sheared and fractured rock at least 2,500 feet (760 m) long, 300 to 700 feet (90 to 210 m) wide, and at least 30 feet (9 m) thick; the body is irregular in outline (see fig. 141, p. 156).

The lower boundary of the shear body is a shear plane or series of shear planes close to or directly on the coal (fig. 47). Around the lateral borders of the shear body, the lower shear surface curves upward, cutting across the bedding at a low angle oblique to the bedding, as it is exposed in roof falls around the margins of the shear body (fig. 48-52).

Coal and rock below the shear body show few visible signs of deformation (figs. 53-55). The top surface of the coal is gently undulating, as it is elsewhere in the mine, and no unusual larger structures have been observed. Roof rock below the shear body likewise shows features, such as roll patterns, like those found throughout the mine. At one location, the top of a large roll filled with medium-gray shale was truncated by the shear body (fig. 52). This indicates that the formation of the shear body postdates the formation of the rolls.

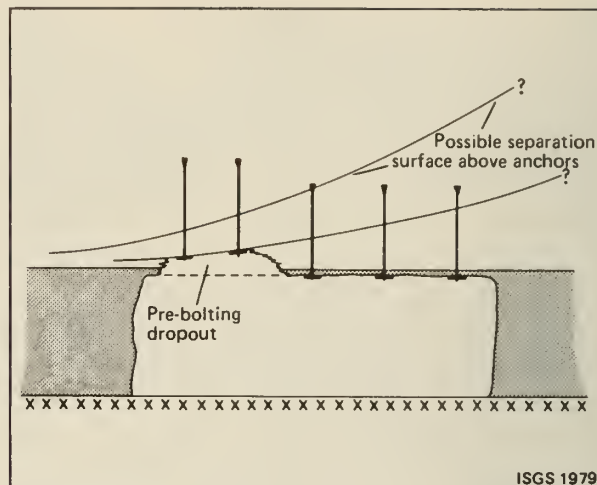


Figure 45. Roof failure caused by low-angle shear surfaces. The influence of this type of shear surface on roof instability overwhelms most other factors causing failure. The roof is prone to fall because: (1) the wedge of rock between shear surface and mine opening may exceed the tensile strength of the shear surface, (2) the wedge may separate before support can be installed, (3) the weight of the supported wedge may fail the anchor, or (4) the weight of the supported wedge may fail the roof bolt.

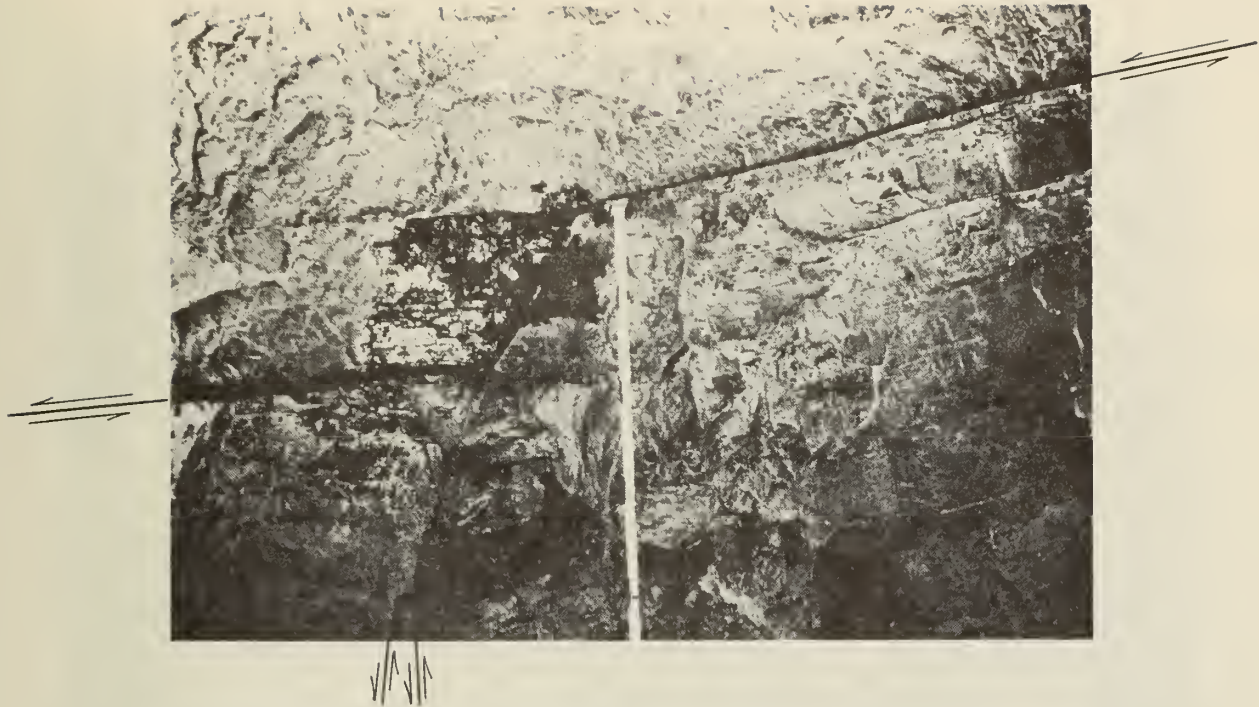


Figure 46. Shear plane parallel to bedding in Herrin (No. 6) Coal appears to have offset a high-angle normal fault and later to have been offset itself along the lower branch of the same high-angle normal fault. Location: southern Illinois, "Quality Circle," mine C.

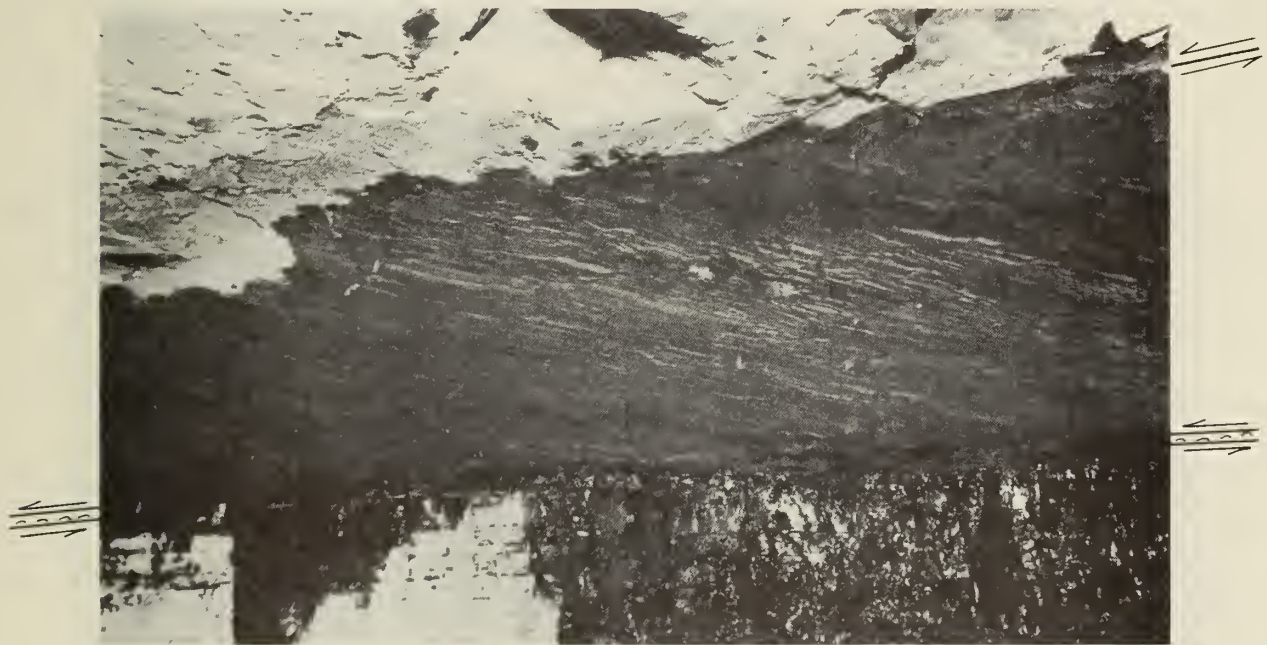


Figure 47. Finely laminated silty shale with numerous small, narrowly spaced, low-angle normal faults in the "shear body." Two major shear surfaces border the sheared block. One major shear surface is almost horizontal and is oriented parallel to the bedding. It forms the immediate coal-roof contact, but also truncates the inclined laminations of the silty shale. The coal itself is not visibly affected by the deformation. The second major shear surface runs about parallel to the many small faults in the laminated shale just below the rock-dusted (white) portion of the roof. Location: southern Illinois, "Quality Circle," mine B.



Figure 48. Almost undisturbed Herrin (No. 6) Coal and some beds of finely laminated silty shale truncated by a northward-dipping (to the left) set of major shear surfaces and overlain by the shear body. Location: southern Illinois, "Quality Circle," mine B.



Figure 49. Detail of figure 48. Note the associated drag folds (soft-sediment folds above compass) within the shear zone.

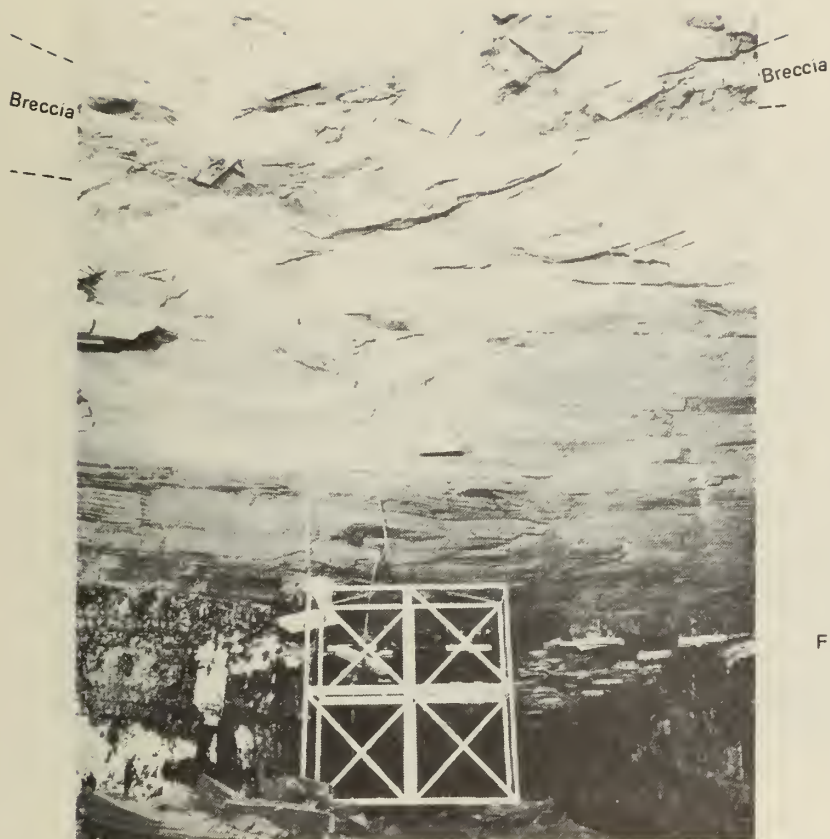


Figure 50. Roof fall in shear body of mine B. The Herrin (No. 6) Coal is overlain by several feet of undisturbed laminated Energy Shale. The shear body (at top) is Energy Shale that has been narrowly penetrated by low-angle shear planes. It did not hold anchors of roof bolts, and failed.

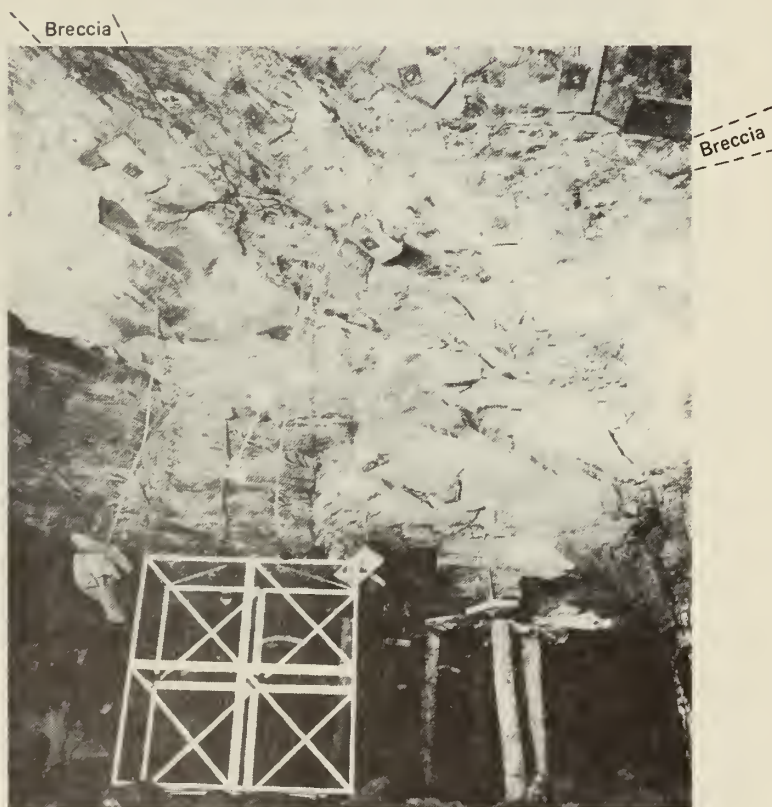


Figure 51. Shear planes cutting lower laminated Energy Shale. Both figures 50 and 51 show breccia zone along major listric shear surface. Second set of roof bolts have been anchored above shear body, probably in undisturbed Energy Shale. Location: southern Illinois, "Quality Circle," mine B.

Figure 52.

Nearly horizontal shear zone of a set of shear surfaces enclosing dragged, folded, and sheared dark-gray shale; main shear movement of each upper shear bed is toward the left and has truncated the top of a major roll of silty, medium-gray shale. This truncation indicates that formation of the shear body continues after or even postdates formation of rolls; however, small low-angle antithetic faults penetrate the shear zone of dark-gray shale and remnant of roll, so these postdate both roll and shear zone. Section from bottom of photo to top: (A) coal slightly deformed by fault in roll (left side of photo), (B) laminated silty shale within the roll, (C) folded, sheared, and intensively contorted dark-gray shale in shear zone, and (D) greenish claystone of main shear body. Location: southern Illinois, "Quality Circle," study area 5, mine B.

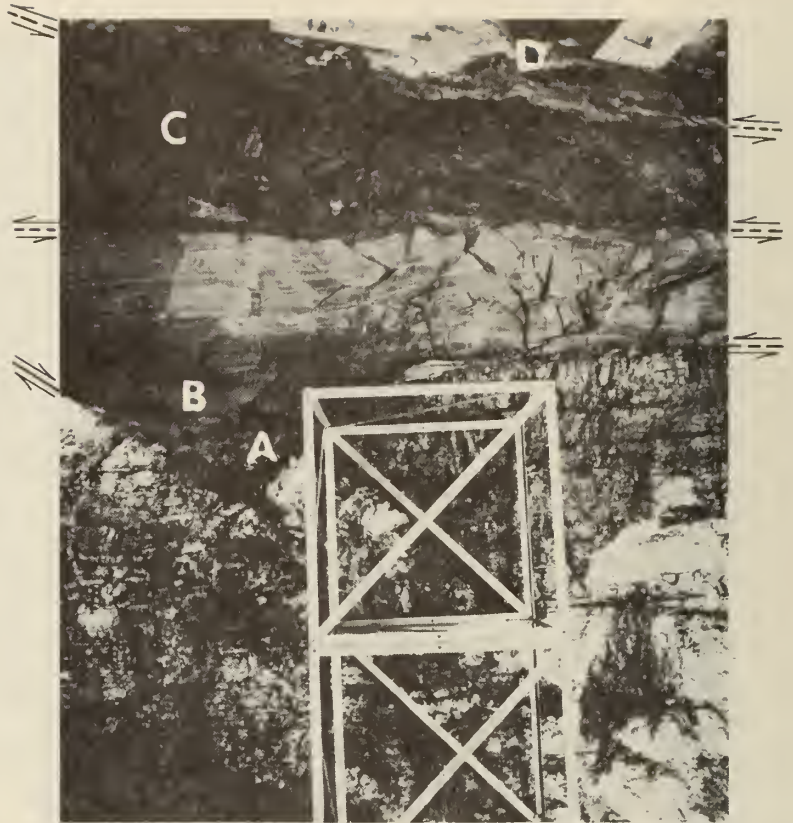


Figure 53.

Microfaulted laminated silty shale and siltstone. Low-angle and high-angle shear planes are adjacent and are of a single deformational action. The microfault pattern resembles the lower portion of seismites described by Seilacher (1969). Mass movement in general is downward, and each lower portion has moved laterally toward the south (left in photo). Major shear plane is subparallel to bedding just above coal. Coal itself is affected only at very top. Location: southern Illinois, "Quality Circle," study area 5, mine B.

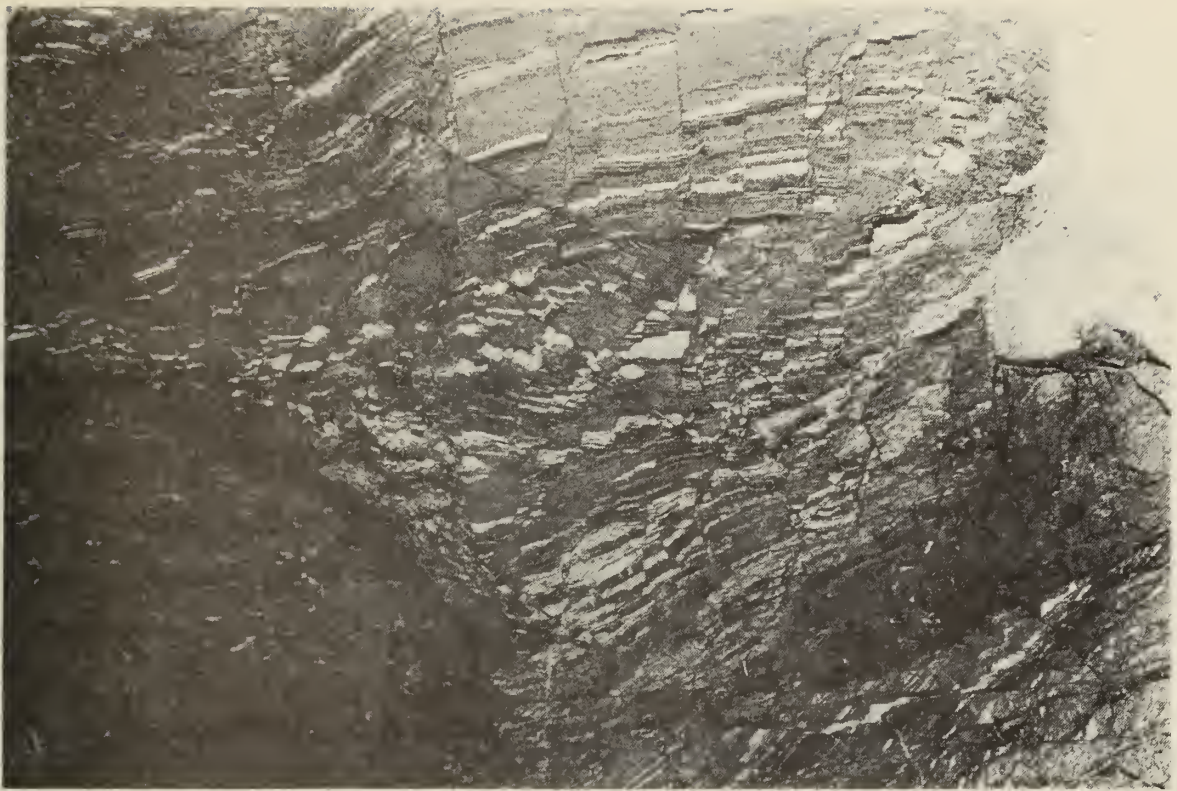
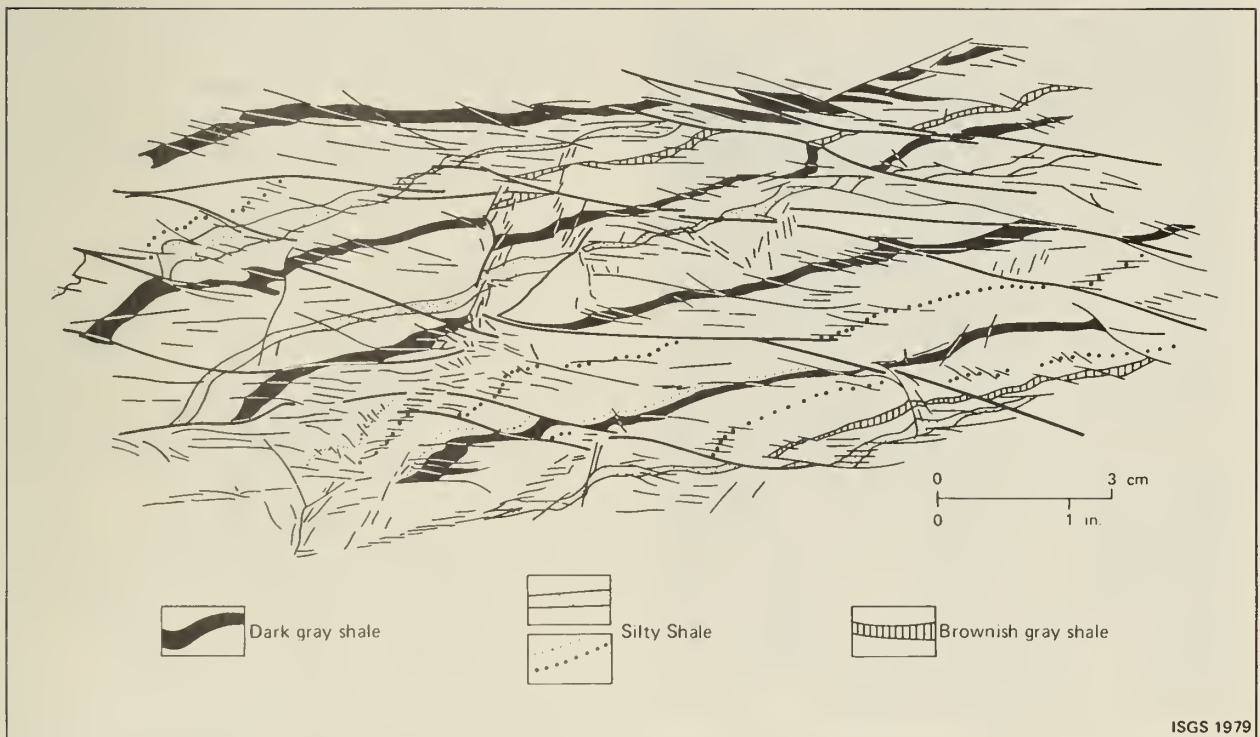


Figure 54. Detail of figure 53.



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Figure 55. Microfaulted laminated silty shale and siltstone. Low-angle shear planes prove lateral extension of rock layers. Strike and dip of these planes are shown in figure 56. Resembles lower portion of seismites as described by Seilacher (1969). Location: in Energy Shale immediately above Herrin (No. 6) Coal, "Quality Circle," southern Illinois, mine B.

Within the shear body itself only a peculiar deformational rock facies has developed. We refer to this postdepositional, alteration facies as the "greenish claystone facies." The rock is a significantly soft, claystonelike shale, displaying poorly defined, highly contorted bedding; however, it is intensively sheared by narrowly spaced high- and low-angle to subhorizontal shear planes (figs. 53-55). The rock closely resembles a seismite, which Seilacher (1969) defined as a rock disturbed by earthquake activity. The rock contains large isolated blocks of other lithologic facies; many of the blocks are crushed, brecciated, or contorted, and others are deformed to phacoids (Voigt, 1962). Some fragments of the greenish claystone facies are firm and silty and contain fine flakes of mica. Large plant impressions and inclusions of dark carbonaceous debris are common 10 to 20 feet above the coal. This contrasts with other facies of the Energy Shale, which contain carbonaceous material only in the lowermost foot.

The shear body displays many features of deformation, ranging from plastic to brittle. Plastic deformation is characterized by abundant recumbent tight folds and contortions (fig. 49), especially along the lower shear plane. Brittle failure is represented by microfaulting (figs. 47 and 54) and brecciation (fig. 50 and 51). Transitions between plastic and brittle failure are common.

The small-scale structural trends in the shear body are difficult to discern. A fair degree of consistency is shown in directions of striations on shear planes, which are represented by arrows pointing in dip direction on the maps (see fig. 141, p. 156). In most places the striations trend approximately perpendicular to the boundary of the shear body. Therefore, more divergence is seen in the western part of the mapping area, where the shear body apparently terminates. The strike of most of the shallow-angle shear planes in the eastern half of the mapping area is roughly east-west, parallel to the borders of the shear body. In addition to conventional mapping, a total of six stereopairs (compare figs. 50-52) at four sites provided measurements of strike and dip of shear and bedding planes. Schmidt net diagrams (fig. 56) reflect the orientation

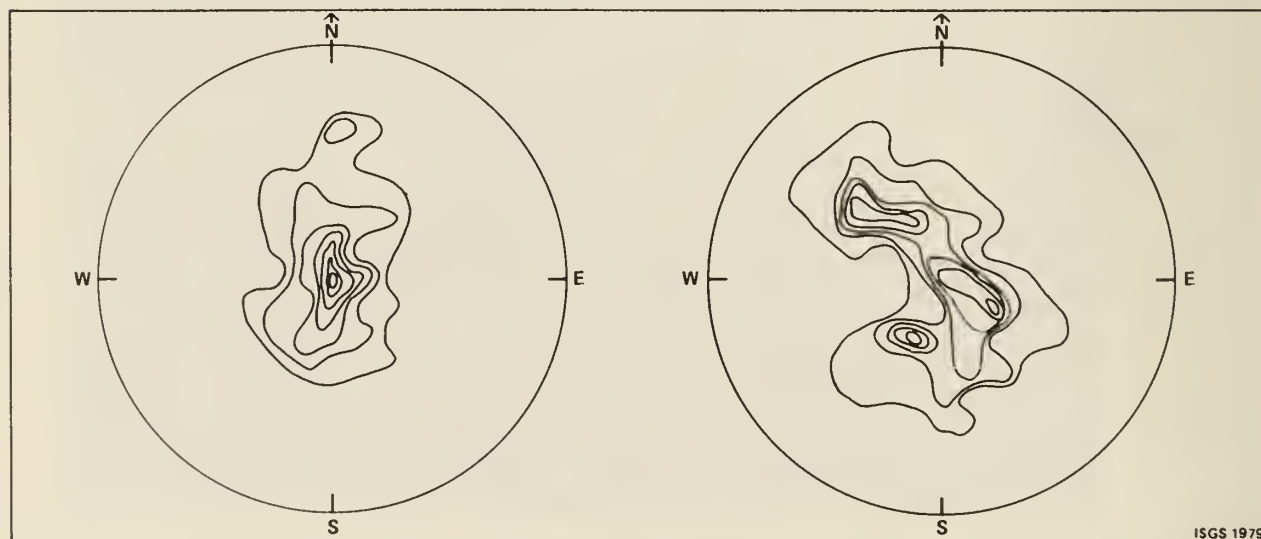


Figure 56. Schmidt net density diagrams from photogrammetrically collected data of shear planes in the shear body of study area 5, mine B. (A) Synoptical plot of poles from three populations of shear planes (stereopairs 1, 2, 3), 117 shear planes, isopycnos: 1.7-3.4-5.1-6.8-8.5 percent. (B) Plot of poles from one population of shear planes (stereopair 6) 55 shear planes, isopycnos: 1.8-3.6-5.4-7.2-9.0-10.8 percent.

of the interior low-angle shear surfaces similar to that mapped in the area. A symmetry around this trend also is shown, with two maxima of low-angle shear surfaces on each side of the shear body's axis.

The strike of most shear surfaces also varies toward the termination of the shear body in the west. The strike first trends northwesterly and is again parallel to the borders of the shear body in that area. The point of bending occurs near a moderate "hill" in the coal seam.

As is clear from the maps (figs. 140 and 141) in the following chapter, roof control is extremely difficult within the greenish claystone facies and the shear body area. Roof falls commenced as soon as the area was opened and are continuing. The falls are commonly 15 to 20 feet (4.6 to 6.1 m) high, and top out at the highest major shear surface. Roof instability extends out of the mapped area of the shear body toward the southeast of study area 5. There the top is as unstable as in the heart of the shear body. The immediate roof is fairly strong shale, but the shear body with its broken rock lies just above roof bolt height. In many places of the shear body area, the mine openings have been kept open only by extensive cribbing. The weakness of the crushed rock itself, combined with the great abundance of shear planes, is obviously the cause of the roof instability. Although no other shear bodies of this type have been found in Illinois underground mines, several similar occurrences have been recognized in outcrops and in strip mines. Shear bodies in the Pennsylvanian System of Illinois may be fairly common. A shear body is a type of mining hazard that should be easily recognized in a drill core by the abundance of fractures and shear planes.

The origin of the shear body is open to question. Possibly it is a gravitational slide deposit. When sediments are deposited rapidly on a sloping surface, even if the slope is gradual, shallow slumping or large sheet and flow masses may occur. Slides can be triggered by excess of load, undercutting by stream erosion, local "explosion" caused by escape of water or gas from deeper sediment, or earthquakes. The jumbled and displaced roof rock in the shear body in study area 5 of mine B suggests a gravitational slide deposit, which poses a threat to roof stability.

Joints. While joints in roof rocks are considered to have a major influence on roof stability in many of the world's coal mines, this appears not to be the case in the mines with a gray shale type of roof (fig. 57). This is evident in study areas 4 through 7, where there are no significant associations, by direction, frequency, or spacing, between jointing and roof falls.



Figure 57. Narrowly spaced parallel joints in the dark-gray shale facies of the Energy Shale. Joints are normal to bedding planes and strike N 50°-60° E. Location: mine Q, "Quality Circle," southwestern Illinois.

At mine B joints are abundant in the dark-gray shale and are rare in other facies of the Energy Shale. They are spaced from a few inches to about a foot apart and seldom penetrate more than a foot into the roof. Two to three feet is exceptional. By far the dominant direction is that of the joints in mine B, as in other mines studied, N 060°-080° E. These joints contribute to minor slabbing of the immediate roof rock, but cause no major roof falls.

The rather massive shales at mine C are practically devoid of joints. The N 060°-080° E trend again dominates. Most of the joints are vertical, but some are at angles as low as 45° in areas where the rock layers are tilted or folded, as around major rolls. In most such cases the joints are normal to the bedding. In some places fractures or joints not perpendicular to bedding, and without indications of movement, are present. These types of joints intersect with bedding surfaces to form wedge-shaped rock bodies, which are a minor source of roof instability.

In only a very few cases could joints be blamed for causing roof falls. One such place is in an area of transitional gray shale-black shale-limestone roof in mine I, where joints are spaced as closely as a centimeter apart, and penetrate several meters upward through dark-gray shale and medium-gray shales of the Energy Shale into the black fissile shale (Anna Shale). Figure 58 shows fracturing and roof falls along narrowly spaced sets of joints in mine P. On the whole, however, joints are a minor source of roof instability.

Major faults and fault systems

Major faulting in the Illinois Basin Coal Field occurred primarily along three fault zones: the eastern part of the Shawneetown Fault Zone and the Cottage Grove Fault System, which extend almost east and west through southern Illinois, and the Rend Lake Fault System (Krausse and Keys, 1977), which trends almost north and south from southern Franklin County northward into Jefferson County (figs. 3 and 59). Portions of these fault zones are exposed in underground mines in Herrin (No. 6) Coal.

Although no detailed mapping was performed in major fault systems for this study, the Rend Lake Fault System was examined in several mines, and is worthy of further discussion. The Rend Lake Fault System is a north-south-trending zone of normal faults

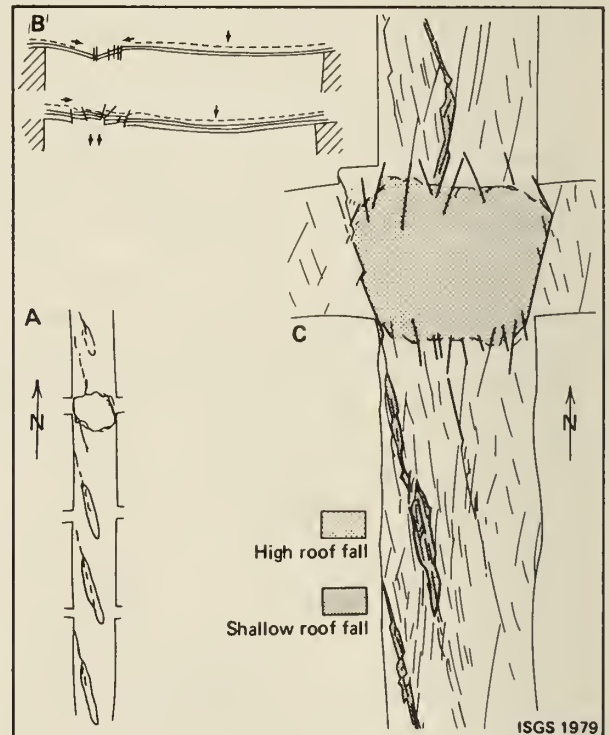


Figure 58. Zones of weakness and roof fall development: (A) Early stage of development, the beginning in an echelon pattern, along zones of narrowly spaced joints. The roof fall is largest and highest at the intersection. In some areas of the mine these en echelon roof falls join together in a continuous north-south-oriented roof fall. (B) Section of strata in which kink zones and roof falls develop along narrowly spaced joints and slips. (C) Joint pattern and en echelon roof fall pattern along N 160°-170° E-trending zones. Two sets of joints in dark-gray shale of the Energy Shale (155° to 160°/83° to 90° SW and 20° to 25°/83° to 90° SE). Location: "Quality Circle," southern Illinois, mine P.

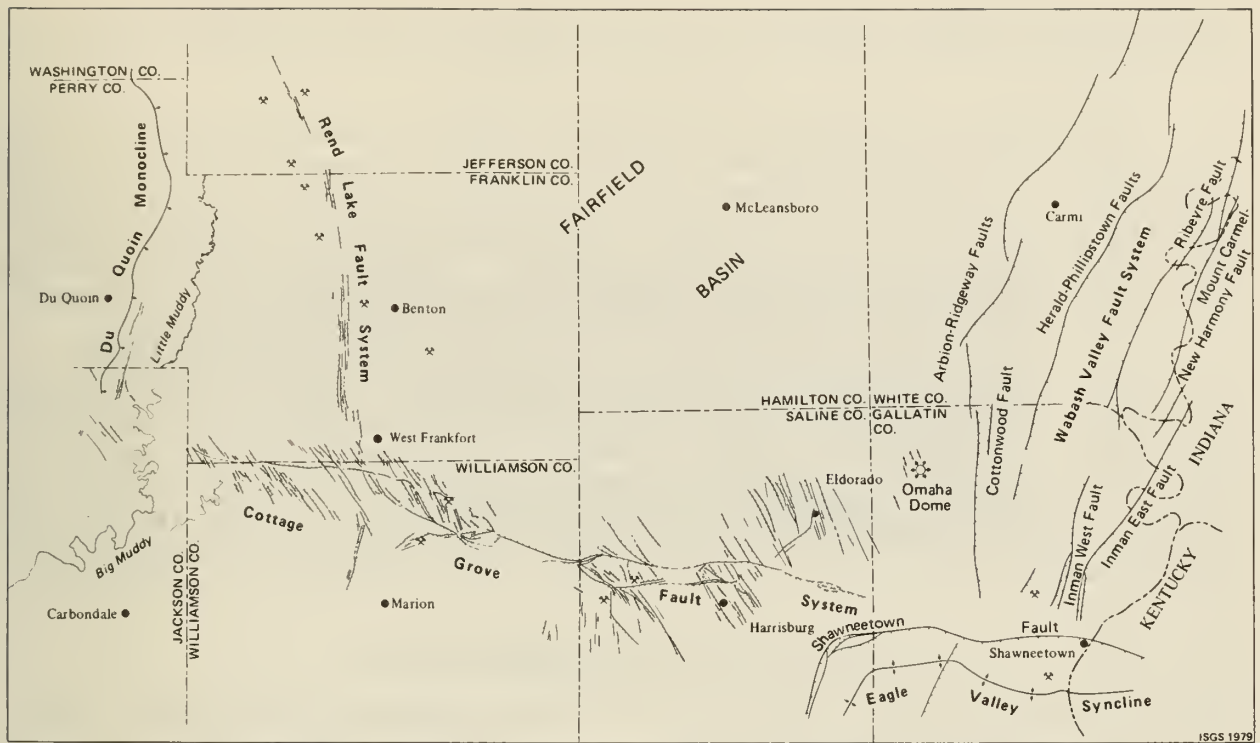


Figure 59. Major fault systems and structures in southern Illinois. (After Stonehouse and Wilson, 1955.)

in Franklin and Jefferson Counties, Illinois. It lies just west of Rend Lake, a large reservoir for which it is named. The fault system is located only from exposures and test drilling in underground coal mines; no surface expression is known. The fault system ranges from a few hundred to about a thousand feet (100 to 300 m) wide. Near West Frankfort it branches off from the Cottage Grove Fault System and extends northward for at least 24 miles (39 km). Along strike it not only varies in width, but also in number of faults and magnitude of displacement. Along most of its extent, the main displacement is down to the east, but the Rend Lake Fault System includes faults downthrown to the west as well. The most characteristic setting is a large normal fault downthrown 30 to 60 feet (9 to 18 m) to the east, usually associated with a number of minor antithetic and synthetic normal faults on either side. No individual fault is continuous along the entire length of the system. The faults diminish in throw in either direction along strike until they become structures with minor displacements at the top of the coal seam, below which the fault plane branches downward in a dendritic pattern of extension fractures ("goat beard"), which have no vertical displacement at the bottom of the seam. The major faults appear to lie in an en echelon pattern. In places the faulted and sheared zone consists of a zone, a centimeter to a meter in width, of highly fractured or pulverized rock with very little displacement.

Individual faults in the Rend Lake Fault System generally strike about north-south (165° to 180°), and dips vary from vertical to 45° toward the east or west. Locally fault planes are overturned, effectively forming high-angle reverse faults. In some places the dip along a fault plane turns as much as 20° at a single exposure in a mine entry. Normal drag-folding of adjacent strata occurs but is not prominent. "False drag" and minor folds associated with the faults have been observed, yet they are not common. Zones of gouge

or breccia of finely crushed coal and fragments of rock accompany the fault planes, but seldom exceed a few inches in width.

Predicting the location of individual faults of the system is difficult because of a lack of continuity and the en echelon pattern of the major displacements. Mines have planned entries or panels around straight-line projections of the Rend Lake Fault System, only to have the faults appear several hundred feet away from the predicted location. Drilling from the surface does not always alleviate the problem because individual faults tend to be small, and displacements may be down to either the east or west, or both.

The principal mining problem associated with the Rend Lake Fault System is physical displacement of the coal seam. The faults generally have not caused many major roof problems, because in many cases the entire fault system is crossed in the shortest possible distance by grading the entries through rock, with no crosscuts in the faulted zone. Problems easily arise where the faults tend to die out and branch into minor shear planes with little displacement. In such zones, mining is not likely to stop, but roof falls are probable.

Black shale-limestone roof types

DESCRIPTION OF LITHOLOGY AND FACIES OF THE BLACK SHALE-LIMESTONE ROOF TYPES

The black shale-limestone roof sequence of Herrin (No. 6) Coal comprises a large number of lithologic units and of rock stratigraphic members that are highly variable in thickness, areal distribution, and characteristics. Seven members are of primary relevance to roof stability: the Anna Shale (lowest), Brereton Limestone, Jamestown Coal, Conant Limestone, Lawson Shale, Anvil Rock Sandstone, and the Bankston Fork Limestone Members. Figure 60 is a schematic of the lateral and vertical relationship as found in study areas 1 to 3 in mine A. The effectiveness of a roof control plan depends on an understanding of the sequence, the lithologies, and the variable characteristics of the lithologic units.

The lenticular shape of the black shale and argillaceous limestone bodies as found in mine A prevails over large areas of the Illinois Basin Coal Field and is an important structural element of this roof type. Although the black shale and the argillaceous limestone in places lie side by side, the limestone normally overlies or at least partially overlaps the older Anna Shale. Study area 2 in mine A is an especially good example of the partial overlapping (fig. 129, p. 131).

Most of the higher units are more continuous, although they vary greatly in their lithology and thickness, which apparently depends on thickening or thinning of underlying rock units. Probably the most persistent unit, which has almost constant thickness in the vicinity of mine A, is the Conant Limestone. Thickness of the Lawson Shale, on the other hand, varies greatly—from 2 to 15 feet (0.7 to 5 m). It becomes thinner above very thick lenses of Brereton Limestone and thickens in places where the Brereton Limestone and Anna Shale are thin or absent. The Bankston Fork Limestone overlies most of this sequence; its local variability and its response to variations of the rock members below are not yet well known.

The limestones are the strongest units in the sequence. Roof falls are extremely rare where the limestone of the Brereton Limestone is thick. Gray

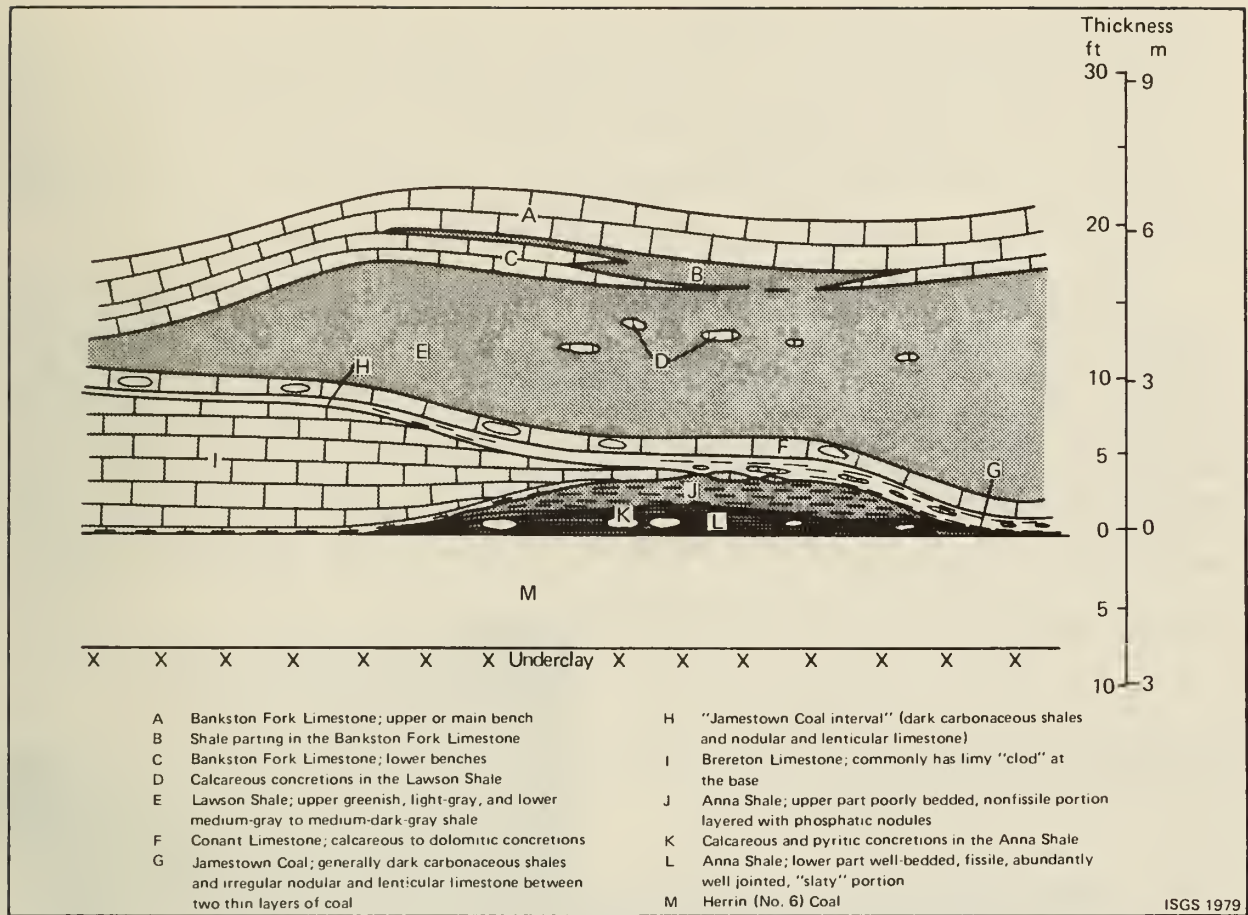


Figure 60. Black shale-limestone roof; sequence of rock stratigraphic members at mine A.

shales and siltstones of the Lawson Shale, on the other hand, are apparently the weakest layers of the sequence. Where gray shales closely overlie the coal (no Brereton Limestone, very thin Anna Shale, Jamestown Coal, and Conant Limestone), roof stability decreases drastically.

The structural features of coal and roof rock in areas having the black shale-limestone type of roof are distinct from those having the gray shale type of roof. Distribution, frequency, density, pattern, and orientation of deformational elements are highly dependent upon the roof lithology.

Many of the characteristics of the rocks found overlying the Herrin (No. 6) Coal and their relationships to each other have not been described before. The accumulation and composition of coal-forming materials are known to have influenced the properties of the younger rock strata in the roof.

Top coal

Much of what applies to top coal below gray shale roof is true for black shale-limestone roof as well. The practice of leaving top coal under black shale-limestone roof is not as common as under gray shale roof, simply because the coal is usually not as thick as it is under the gray shale roof. Places

where top coal was left were mapped as "T" on our lithologic maps (figs. 118, 125 and 133). Wherever top coal remains, geologic mapping becomes difficult because many structural features that can be recognized at the contact of the coal and roof diminish downward into the coal. Therefore, in "top coal" areas, various secondary indicators, for instance, certain peculiar patterns of cleats below concretions, "goat beards," very small faults, or clay dikes in the coal are used as guides to deformational structures in the roof strata.

During mapping in mine A we discovered that where a foot or more of top coal had been left in entries driven by a boring type of continuous miner, the entries have needed less maintenance over the years. Particularly in areas of black shale with thin or no limestone above, thick top coal probably aids roof control. Yet, it is not clear how much of the improved performance can be attributed to top coal left and how much to the arched shape of the entries. Rib rashing also seems to be less prominent in bored entries, whereas in openings mined by the ripper type of continuous miner, the higher vertical walls may rash off in large slabs, which cause difficulties for safety and maintenance (figs. 16 and 17).

"Bastard limestone"

Of very local occurrence is the so-called "bastard limestone," an argillaceous limestone that lies in and at the base of the Anna Shale and in places interfingers with the upper layers of the Herrin (No. 6) Coal seam (figs. 61 and 62) to form flat lenses. In mine A the "bastard limestone" is generally dark brownish gray to almost black and contains small, distinctive, brown-weathering fossils. It varies from very hard to soft and flaky and in places grades into calcareous shale. Most lenses of "bastard limestone" are only a few feet in diameter and no more than a foot thick. The largest lens mapped covered an area about 100 feet by 50 feet (30 m x 15 m) and was up to 2 feet thick (0.6 m). "Bastard limestone" was also observed in small lenses at mine E, mine H, as well as in drill cores from various parts of the state on top of gray shale rolls and underneath black, fissile shale.

In mine A we found that "bastard limestone" was often deposited close to the lateral lithologic boundaries of black fissile shale and limestone bodies. The presence of "bastard limestone" lenses may indicate a transition between a zone of stable roof

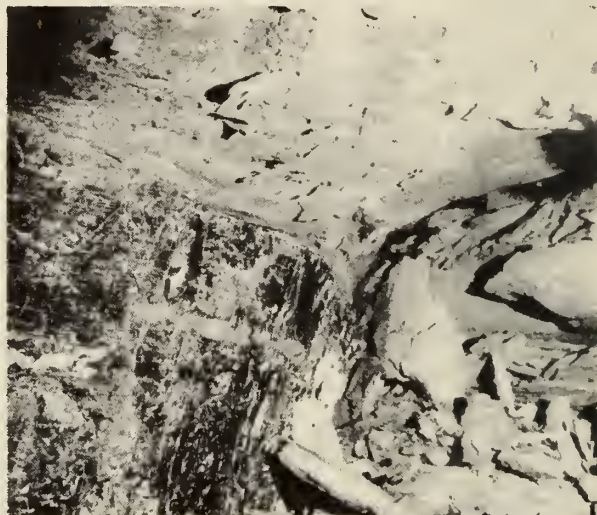


Figure 61. "Bastard limestone" above Herrin (No. 6) Coal consists of dark, brownish, flaky, calcareous shale or shaly limestone with light flecks of fossil debris. Where "bastard limestone" lenses are very large, they are prone to fail and not support the overlying strata, as evidenced by roof fall (right side of photo). Location: mine A, study area 3, west-central Illinois.

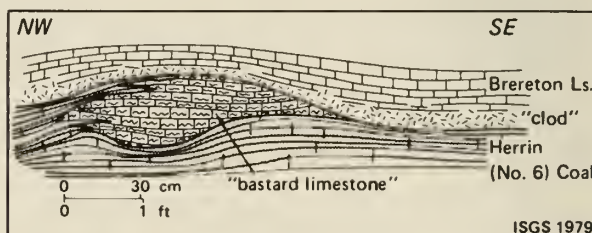


Figure 62. Lens of "bastard limestone" in top benches of Herrin (No. 6) Coal below "clod" of Brereton Limestone. Anna Shale is absent. Location: west-central Illinois, mine A.

protected by a thick limestone and a zone of roof instability. The main hazard of the "bastard limestone" is that it may be mistaken for the Brereton Limestone, which usually makes excellent roof. If not recognized for what it is, "bastard limestone" may be inadequately supported.

Black shale roof of Herrin (No. 6) Coal (Anna Shale)

The lowest roof rock unit of importance that normally forms the immediate roof is a black fissile shale of the Anna Shale. It is black, hard, smooth, fissile, and carbonaceous, and contains abundant small phosphatic nodules. Black shales overlie most of the coal seams of Illinois. Miners and drillers generally call them "slate." The black shale above Herrin (No. 6) Coal was studied in greatest detail at mine A, where it occurs in irregular lenses several hundred to over a thousand feet wide and is usually overlain by the Brereton Limestone, at least along the fringes of the lenses. The lateral transitions are normally abrupt at the edges of the lenses, as found in study area 2, where the black shale increases in thickness from a knife-edge on the track entry to three feet on the next entry, which is 80 feet (about 25 m) to the northeast. In some areas, however, the change in the thickness of the black shale is more gradual than in study area 2. In the central portions of the lenses, the black shale is usually two to three feet (60 to 90 cm) thick for hundreds of feet and locally thickens to over four feet.

In mine E, a strip mine, the Anna Shale appears to form lenses similar to those in mine A (fig. 63). In some areas the Anna Shale displays several



Figure 63. Cross section in black shale-limestone roof: (A) interval of the Piasa Limestone Member and the unnamed gray, green, ocher, and variegated shales below, (B) Bankston Fork, with two limestone horizons, (C) greenish gray mottled and dark gray Lawson Shale, (D) Conant Limestone, (E) shales, argillaceous limestones, dark-gray carbonaceous shales ("Jamestown Coal interval"), (F) Brereton Limestone (lenticular), (G) Anna Shale (lenticular), and (H) Herrin (No. 6) Coal. The Bankston Fork and the Conant Limestones are fairly continuous and regular in thickness, whereas the Anna Shale and Brereton Limestone are lenticular, and wedge. Above the left aluminum frame (control in photogrammetric mapping), the Brereton Limestone has pinched out on both sides above an Anna Shale lens. Location: highwall of mine E in southwestern Illinois.

distinct subunits (fig. 64). The lowest subunit above the coal consists of black, hard, fissile shale that contains abundant vertical joints and concretions. When the Anna Shale is thick, this lower fissile shale layer is one to two feet (30 to 60 cm) thick. Where the Anna Shale is less than a foot thick, it is generally fissile throughout.

Where the Anna Shale is thick, a somewhat mottled, poorly bedded, and fairly weak very dark gray shale overlies the hard fissile black shale (figs. 65 and 66). This thin upper deposit is variable in thickness (0 to 3 feet [0 to 0.9 m]) and locally contains abundant syneresis cracks. At mine A the upper subunit typically contains two distinct bands of small light-brown phosphatic lenses or nodules (figs. 65 and 66). As the dark mottled gray shale unit with phosphatic nodules thins, the two bands seem to merge into one. Both bands are from 1 to 2 inches (2 to 5 cm) thick. The individual nodules and small lenses within the bands are flattened parallel to the bedding and range from less than an inch to several inches long, and they are $\frac{1}{4}$ to $\frac{1}{2}$ inch thick. One to two such bands of phosphatic nodules have also been observed in other mines of the Illinois Basin Coal Field.

Large spheroidal concretions are abundant in the lower part of the black shale, particularly where the unit is thick (fig. 67). Those found in mine A and mine F are typical for Illinois. They range up to several feet in diameter and may weigh several hundred pounds. They are composed of black, pyritic, and sideritic limestone and are surrounded by curved shear surfaces that allow them to fall readily from the roof (figs. 68 and 69). These concretions are scattered throughout the Anna Shale where the unit is more than a foot thick, but occasionally are concentrated in clusters. They present an obvious hazard that miners counter either by pulling them down or by bolting through them.

The Anna Shale at places has been bioturbated, particularly where it is overlain by the Brereton Limestone. Diagenetic deformational features include clastic dikes and sills, shear planes (slips), low-angle normal faults, "soft-sediment" folds, extension fractures, and joints.

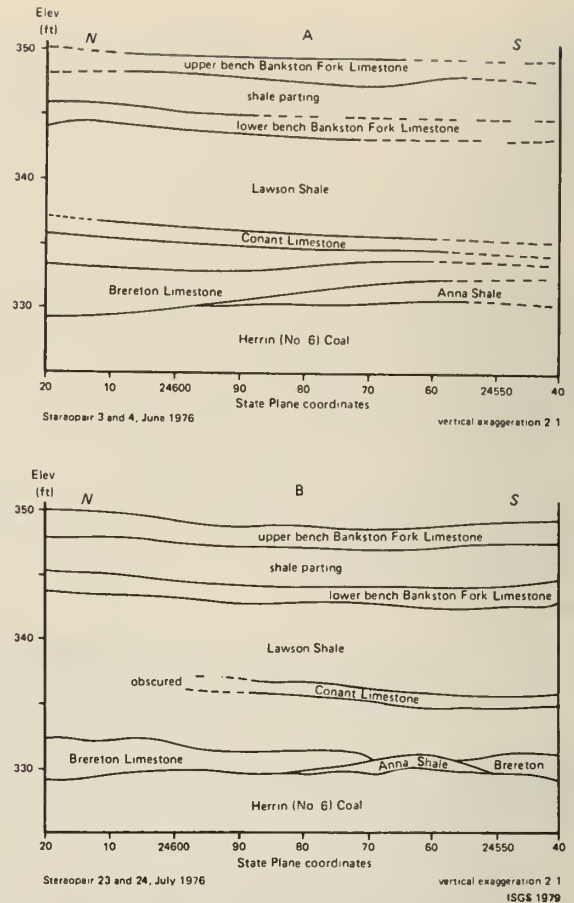
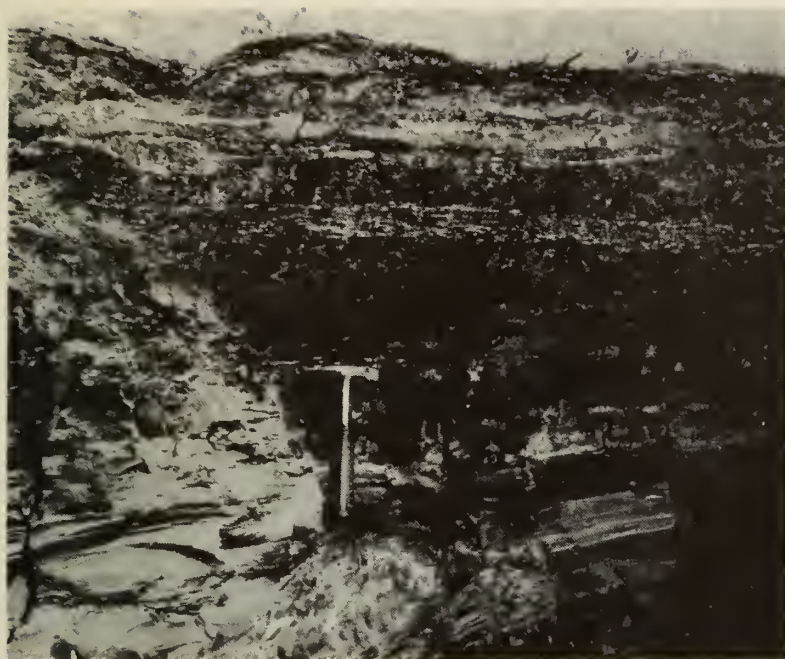


Figure 64. Cross sections from photostereopairs from close-range photogrammetric mapping (see fig. 63) show the position and variation in thickness of the stratigraphic members above the Herrin (No. 6) Coal and their interrelationship. As the highwall advanced, stereopairs were taken repeatedly with the intention of interpolating from section to section to produce a three-dimensional map of the rock bodies. A is from a photo taken in mid-June 1976; B is from a photo taken in July 1976.. Location: highwall of mine E in south-western Illinois.



Conant Limestone

"Jamestown Coal interval"

Brereton Limestone

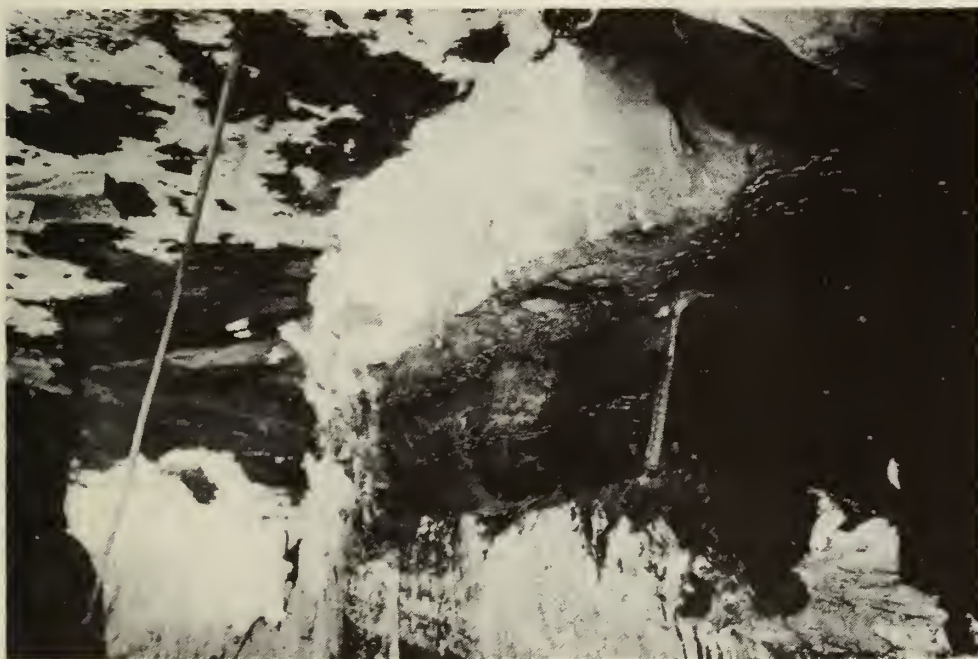
P₂

P₁

fissile Anna Shale

Herrin (No. 6) Coal

Figure 65. Section of immediate roof strata, black shale-limestone roof type in mine A (west-central Illinois). The Conant Limestone (top of photo) is underlain by streaks of Jamestown Coal, with freshwater limestones and some lenses of Brereton Limestone, which in this section is very lenticular and discontinuous. Anna Shale can be subdivided into three lithologic subunits: (1) poorly bedded, strongly mottled, weak, very dark gray shale with upper band of phosphatic nodules (P₂), (2) weak, poorly bedded, less mottled, very dark gray shale with lower band of phosphatic nodules (P₁), and (3) black fissile ("slaty") shale with concretion. The Herrin (No. 6) Coal is lowermost.



Brereton Limestone

P₂

P₁

fissile Anna Shale

Figure 66. Black shale-limestone roof in mine A (west-central Illinois). The Brereton Limestone (appears white because of rock dust) is two feet (0.6 m) thick and overlies thick strata of Anna Shale. The two layers of phosphatic nodules (P₁ and P₂) in the upper, poorly bedded, weak, very dark shale are clearly shown; the black fissile ("slaty") lower shale above the coal is covered by rock dust (white). Total thickness: three feet (0.9 m).



Figure 67. A spheroidal concretion in black fissile shale of Anna Shale. Concretions are found up to a maximum of four feet (1.2 m) in diameter, but average about one to two feet. Since the concretions were harder, heavier, and more lithified before lithification of the surrounding shales, they have caused deformation of bedding in strata (coal and shale) underneath and above. Slickensided surfaces around concretions separate them from strata and increase hazard of fall. Location: mine A, west-central Illinois.

Joints are only locally a problem (figs. 70 and 71). They occur in regular sets from a few inches to a foot apart and usually affect the lower black fissile shale more intensively than the upper very dark gray mottled shale. Throughout mine A the joints strike N 50° E to N 70° E. The shale easily splits between joints into large slabs, which hang precariously from the roof or fall to litter the floor.

Statewide, the black shale is generally considered to be fair to good as a roof material. At mine A most roof problems in the unit appear to be related to structural anomalies and the strata overlying the black shale.

In large areas of west-central Illinois, and particularly in the mapped areas of mine A, the Brereton Limestone is either lenticular and thin, or absent, where the underlying black shale unit is thick. The next higher limestone in the roof sequence is usually too thin (less than one foot in the

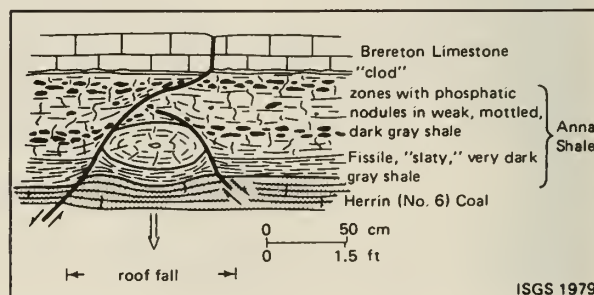


Figure 68. Immediate roof of the black shale-limestone type above the Herrin (No. 6) Coal. Large concretions in Anna Shale associated with small normal faults (slips), which result from differential compaction, cause minor roof falls, and are hazards to coal miners' safety. Location: west-central Illinois, mine A.



Figure 69. Concretions in Anna Shale exposed in a roof fall. "Anna concretions" are most common immediately above the coal. Tilted concretions in lower center of photo are displaced by faulting. Fault probably was caused by differential compaction around a lens of Brereton Limestone (light oval body in center of photo). Small low-angle normal fault is visible from the Lawson Shale (top of roof fall) through the Conant Limestone, the "Jamestown Coal interval," the Brereton Limestone, and the Anna Shale and enters into the coal, steepens, and ends in form of almost vertical extension fractures. Location: mine R on the Western Shelf, southwestern Illinois.



Figure 70. Prominent set of joints in black fissile shale (Anna Shale). Slabs, separated along bedding planes and joints, fall out between the roof bolts. Location: mine N, west-central Illinois.

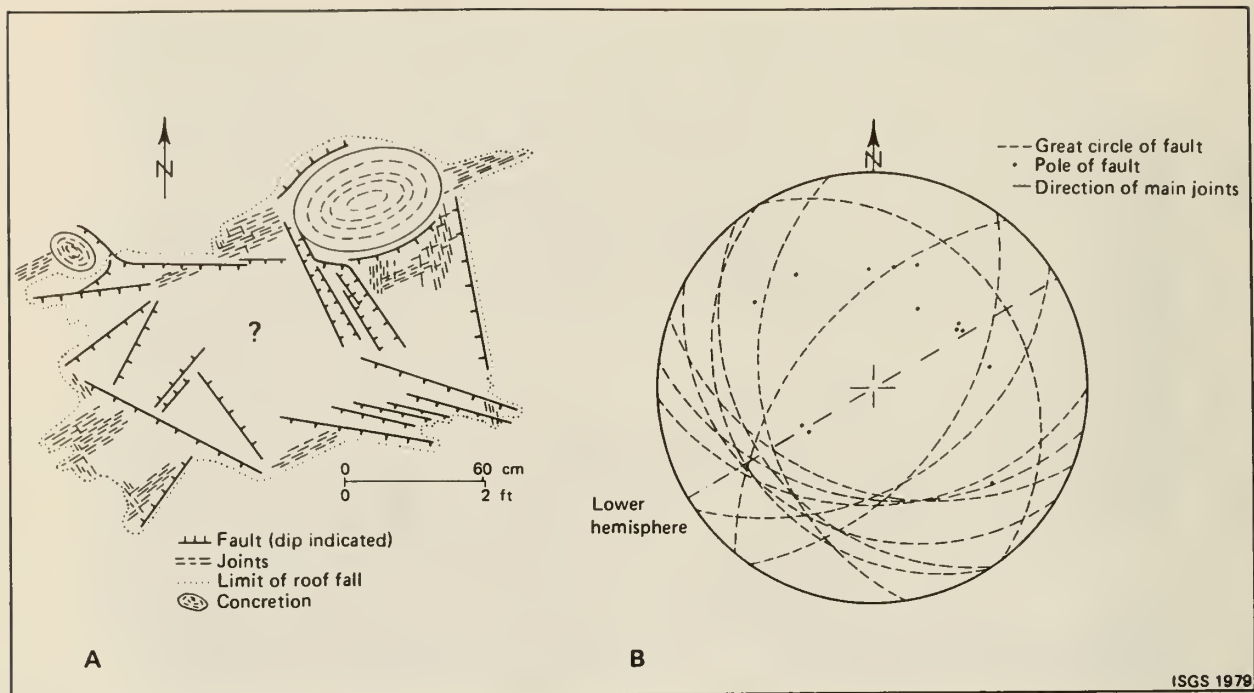


Figure 71. Faults and joints increasing roof fall hazards: (A) shape of roof fall, primarily caused by faults and secondarily by joints in Anna Shale. Faults and joints in the higher fall area could not be determined. (B) orientation diagram (Schmidt net) of the faults and the major joints forming the roof fall. Thirteen faults and mean value of 59 orientation data of joints in Anna Shale were used. Location: west-central Illinois, mine A.

case of the Conant Limestone) or too high above the coal to contribute to roof stability. Most of the largest roof falls in mine A occur in zones where lenses of black shale and limestone overlap and end. These lithologic boundaries are additionally weakened by associated faults and clay dikes, which are most common near the boundaries of the black shale lenses. Roof falls under undisturbed thick black shale and in black shale areas immediately overlain by non-failing limestones are generally shallow and small.

Limestone and "clod" above the black shale
or the Herrin (No. 6) Coal (Brereton Limestone)

Overlying the black shale strata of the Anna Shale in many places is a marine limestone, the Brereton Limestone. The appearance of the limestone varies. In southwestern Illinois, from Williamson through Macoupin Counties, it is characteristically dark gray, argillaceous, fine grained, dense and hard, fossiliferous, poorly bedded, and interlayered with waves or swirls of shale partings. To the north of Macoupin County, it is generally lighter gray, impure, and lacks the wavy shale partings. In mine A, it is commonly massive and fossiliferous. Where the unit is very thick, as along the large faults in study area 1, the upper portion is light greenish gray, coarse grained, and contains large fossil brachiopod shells. In places it resembles the Conant Limestone in texture. The maximum observed thickness of the Brereton limestone is 11.5 feet (3.4 m) at mine A. The normal range of thickness is from zero to 6 feet.

Thick limestone forming the immediate roof is the best possible roof for a mine. This is aptly demonstrated in mine A, where areas having a thick limestone roof are virtually free of falls. This observation also holds for many other active and abandoned mines in Illinois. An abandoned mine in Macoupin County is said to have had few problems in unsupported rooms 50 to 60 feet wide.

In many areas the lowermost portion of the Brereton Limestone consists of a soft, weak, poorly bedded, flaky or slabby, calcareous, medium-gray shale, which the miners call "clod." This "clod" varies from less than one inch to over six inches (1 to 20 cm) in thickness. It tends to spall away soon after exposure to the mine air, and may fall in pieces large enough to cause injury. Eventually the "clod" falls from around the roof bolts, remaining in place only above the header boards (fig. 72). This is the only hazard associated with an immediate roof composed of thick limestone.

The biggest problem in studying detailed lithologies and structures of the Brereton Limestone and the overlying strata in detail is the lack of exposures, which results from the rarity of roof falls in areas of limestone thicker than two feet (60 cm). Our knowledge of lithologies and structures in areas of thick Brereton Limestone is based on drill-hole data and from occasional exposures along major faults in the mines or at overcasts, that is, in places where the roof has been cut away intentionally. The thickest limestone observed to have failed is about $2\frac{1}{2}$ feet at the thick end of a limestone wedge that pinches out (fig. 73). The roof fall appears to have started at the side where the limestone was absent and spread toward the opposite side.

In mine A certain features seem to occur only along the margins of black shale lenses. Near these margins the "clod" layer often becomes highly carbonaceous with fairly thick partings or stringers of coal and large fossilized plant fragments. What we have termed "washouts" are even more striking features (fig. 74). These take the form of pockets cut into the top of the coal seam which are filled with a rather jumbled mixture of "clod" fragments, limestone nodules, black shale, and coal stringers. Splayed-out "riders" of coal are often present along the edges of "washouts." They may be overlain directly by "clod," or a thin layer of black shale may intervene.



Figure 72. Limestone of the Brereton forms stable roof. About the lowest 3 inches (7 to 10 cm) of soft flaky "clod" have fallen, except above the header boards. Location: mine A, west-central Illinois.



Figure 73. Wedging relationship of roof rock layers; both the Anna Shale and the Brereton Limestone pinch out (toward left side of photo). The "Jamestown Coal interval" has thin coal streaks and contributes to bedding separation. The overlying Conant Limestone is too thin to bridge stresses from one pillar to the next. The Lawson Shale is soft and mottled and contains numerous low-angle shear planes and syneresis cracks. Location: mine A, west-central Illinois.

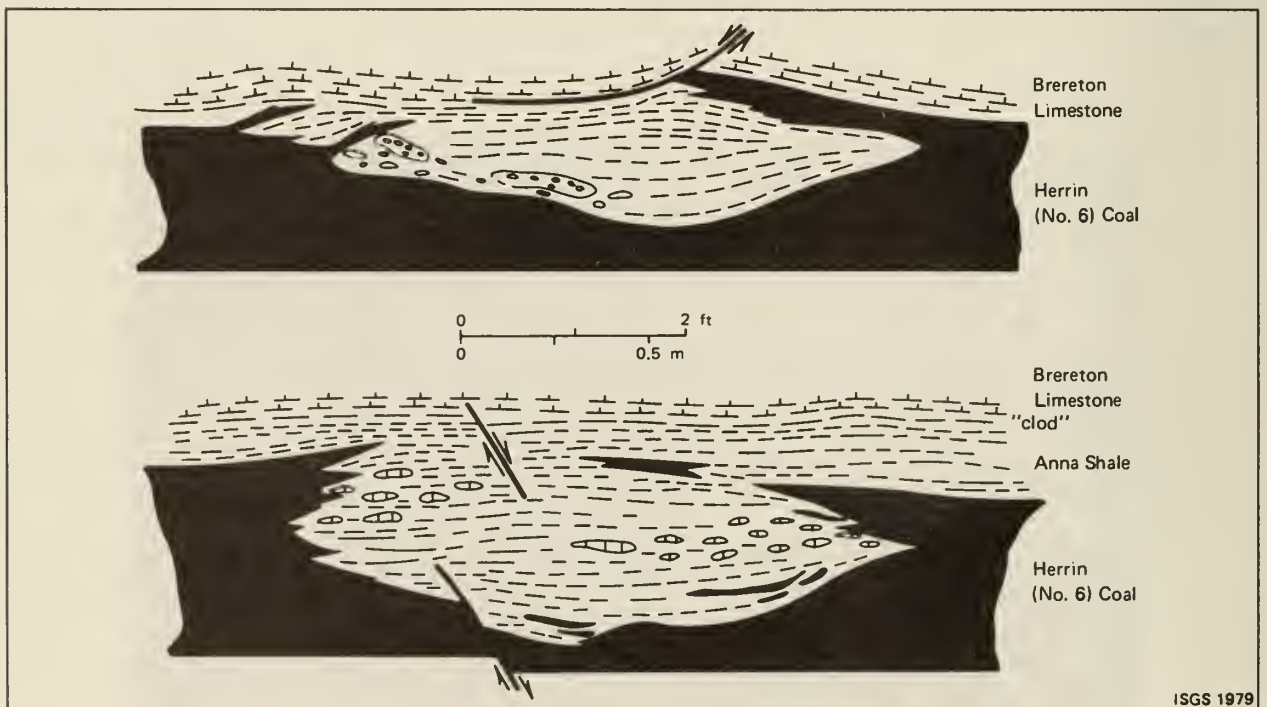


Figure 74. "Washouts," lenses of impure black slaty shale with abundant coal stringers and phosphatic lenses, contain irregular nodules and pockets of brecciated brown limestone in brown shaly matrix. These features are small and uncommon within the top layers of the coal seam below black shale-limestone roof. They are similar to rolls found under gray-shale roof. Location: mine A, west-central Illinois.

"Washouts" are up to 8 feet (2.4 m) wide, averaging 2 to 3 feet, and are from 1 to 1½ feet thick, cutting as much as a foot into the coal. They may have been created by water currents that scoured small channels in the top of the coal and filled the channels with mixtures of the surrounding debris. They resemble lenses of "bastard limestone." They also appear somewhat similar—although on a smaller scale—to the "rolls" that are common in gray-shale roof areas, which indicate a structural rather than sedimentary origin. Coaly "clod" and "washouts" present no special hazard to miners, but they do appear to signal an imminent change from stable limestone roof to less stable black shale roof with its attendant problems.

Coal, shales, and limestone nodules of the "Jamestown Coal interval"

The next higher unit, informally called "Jamestown Coal interval," includes the Jamestown Coal and its associated floor and roof rocks, but does not contain the Conant Limestone or the Lawson Shale. The interval is in many places approximately one foot thick. On the southern part of the Western Shelf it increases to somewhat more than 3 feet in thickness. In most of Illinois the "Jamestown Coal interval" consists of a few inches of shaly coal or black carbonaceous shale interbedded with nodular limestone. In many parts of southern Illinois, the "Jamestown Coal interval" includes limestone or calcareous shale with fresh-water fossils lying between the marine Brereton and Conant Limestones (Allgaier, personal communication, 1975). In Randolph and Perry Counties of southwestern Illinois, coal is often present in the interval, but several feet of shale or claystone may intervene between the Brereton Limestone and the Jamestown Coal. In most of St. Clair County the "Jamestown Coal interval" consists of about a foot of dark shale.

Mine A is the only place the "Jamestown Coal interval" was studied in detail. Most distinctively and typically the interval is a dark gray to black, poorly and unevenly bedded, carbonaceous calcareous shale, with brownish, shaly, nodular or lenticular limestone and shaly coal stringers (figs. 75 and 76). Coal, if present, is most abundant at the top and bottom of the unit, sometimes as two separate stringers of approximately 1 to 3 inches (2–8 cm) thickness. In many parts of the mine, the "Jamestown Coal interval" contains no coal at all, but the shales and limestones are distinctive.

The "Jamestown Coal interval" forms the immediate roof of the Herrin (No. 6) Coal at several locations in study areas 2 and 3. In such places, the lower coaly portion blends into the top of the Herrin (No. 6) Coal, and the contact is difficult to determine. Typical "Jamestown Coal interval" overlies about two feet of the Brereton Limestone as observed at the eastern edge of a large roof fall (fig. 73). The interval varies in thickness and pinches out in places. Where the Brereton Limestone is five or more feet thick, as along most of the major faults in the mine, the "Jamestown Coal interval" is reduced to a few thin, dark, carbonaceous partings between the Brereton and Conant Limestones (figs. 78 and 90).

The "Jamestown Coal interval" is a very weak member of the roof succession at mine A because of its coaly stringers and lenticular fabric. Where it directly overlies the Herrin (No. 6) Coal or thin Anna Shale it causes not only a treacherous slabbing and spalling, but also sets the stage for massive roof falls ten or more feet high. The overlying strata, thin limestone, and weak mottled shales of the Conant Limestone and Lawson Shale are apparently not competent



Figure 75. Jamestown Coal immediately above the Anna Shale. Stratigraphic section: (A) Lawson Shale, (B) Conant Limestone (here consisting of flaky calcareous shale), (C) "Jamestown Coal interval" (two layers of coal streaks separated by carbonaceous shales and nodular lenticular freshwater limestones), no Brereton Limestone, (D) Anna Shale (mainly lower fissile part), and (E) Herrin (No. 6) Coal. Black shale-limestone roof conditions of this type are prone to fail, commonly all the way up to the Bankston Fork Limestone, since no limestone is present in the succession or if present is not strong enough to bridge stresses from pillar to pillar. Location: mine A, west-central Illinois.

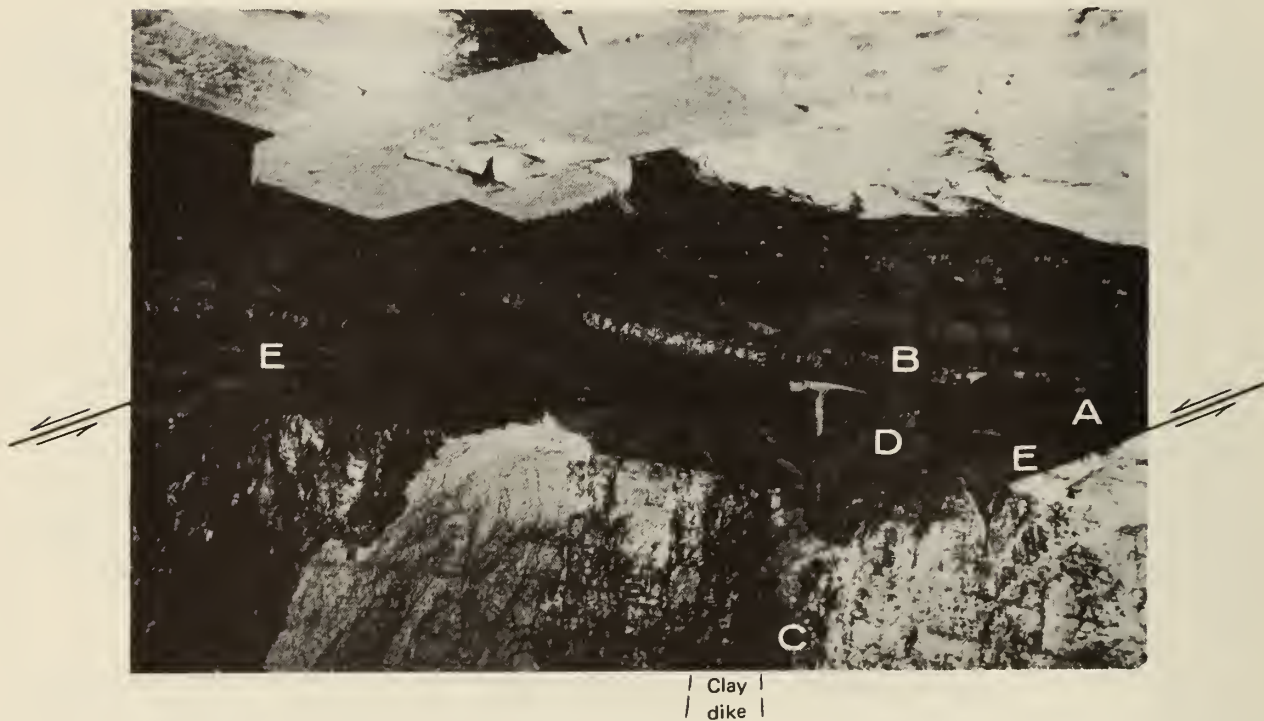


Figure 76. Anna Shale and "Jamestown Coal interval" consisting of black shales and two layers of coal streaks separated by carbonaceous shales and irregular nodules of limestones. Brereton Limestone is only indicated by very thin, light, wedging streaks of calcareous material (A). A small clastic dike (B) penetrates from above the "Jamestown Coal interval" down all the way into the Herrin (No. 6) Coal (C); note brecciation of black shale at clay dike (D) and low-angle normal faults and clay-dike faults, (E), dipping to the left. Location: mine A, west-central Illinois.

enough to carry load across the mine opening. Where the "Jamestown Coal interval" is higher up above the Herrin (No. 6) Coal, is not supported by a thick limestone underneath, and also contains coal stringers, it readily separates along bedding surfaces and slips, causing even higher and more massive roof falls (fig. 75).

Limestone above the "Jamestown Coal interval" (Conant Limestone)

The next younger unit above the "Jamestown Coal interval" is the Conant Limestone. It consists of a coarse-grained, dark-gray, very argillaceous, often dolomitic limestone or a dark-gray, weak and flaky calcareous shale, which is recognized in southwestern and west-central Illinois. In places it resembles texturally a limestone of the Brereton. In south-central and south-eastern Illinois east of the Du Quoin Monocline, the Conant Limestone is absent or thin (less than a foot). The unit also thins to the north and is not recognized in east-central Illinois.

In mine A the Conant Limestone is one of the most uniform and persistent units. It averages 0.8 to 0.9 feet (0.25 to 0.3 m) thick; 1.5 feet (0.45 m) is the maximum thickness observed. The rock is brownish- or greenish-gray, argillaceous, and contains large fossils. Oval, hard, dark, very fine-grained dolomitic concretions or nodules, up to a foot wide and containing abundant calcite-filled fractures, occur near the top of the unit in most localities (fig. 77 and 78). At its base is "clod" similar to, but thinner than, that underlying the Brereton Limestone. Where the Conant overlies very thick Brereton Limestone, as at the large fault in study area 1 (fig. 78), the "clod" is absent. In such areas, only the presence of the "Jamestown Coal interval" allows differentiation of the two limestone units.

The Conant Limestone was not positively identified as forming the immediate roof in mine A. It was assumed that all limestone directly overlying the coal is the Brereton Limestone (or the rare "bastard limestone"), but from underneath, the limestones appear to be nearly identical. The lack of any roof falls exposing Conant Limestone as immediate roof is sufficient evidence that such occurrences are very rare, if they occur at all. Wherever the first limestone above the coal is of the Conant Limestone Member, it is usually the only limestone unit within ten or more feet above the top of the coal. Only one foot of shaly limestone is insufficient anchor to roof bolts and provides little protection against massive falls of the overlying shales or siltstones.

Gray shales, siltstones, and sandstones
of the black shale-limestone roof sequence (Lawson Shale and Anvil Rock Sandstone)

Strata of gray shales, siltstones, and sandstones, which are younger and usually overlie the Conant Limestone, are the most hazardous interval of the black shale-limestone roof sequence. They are facies equivalents in the Lawson Shale and the Anvil Rock Sandstone Members. Where the black shale or the limestone or both are absent below the Conant Limestone, the gray shales, siltstones, and sandstones are found very close to or in places even directly upon the coal seam. The stability and performance of the roof in such areas is very similar to that of the gray shale type of roof.

The interval of gray shales, siltstones, and sandstones of the Lawson Shale and Anvil Rock Sandstone includes a wide variety of rock types of variable thickness. In large parts of the Illinois Basin, the interval includes from 40 to more than 100 feet (12 to more than 30 m) of gray micaceous shale, siltstone,

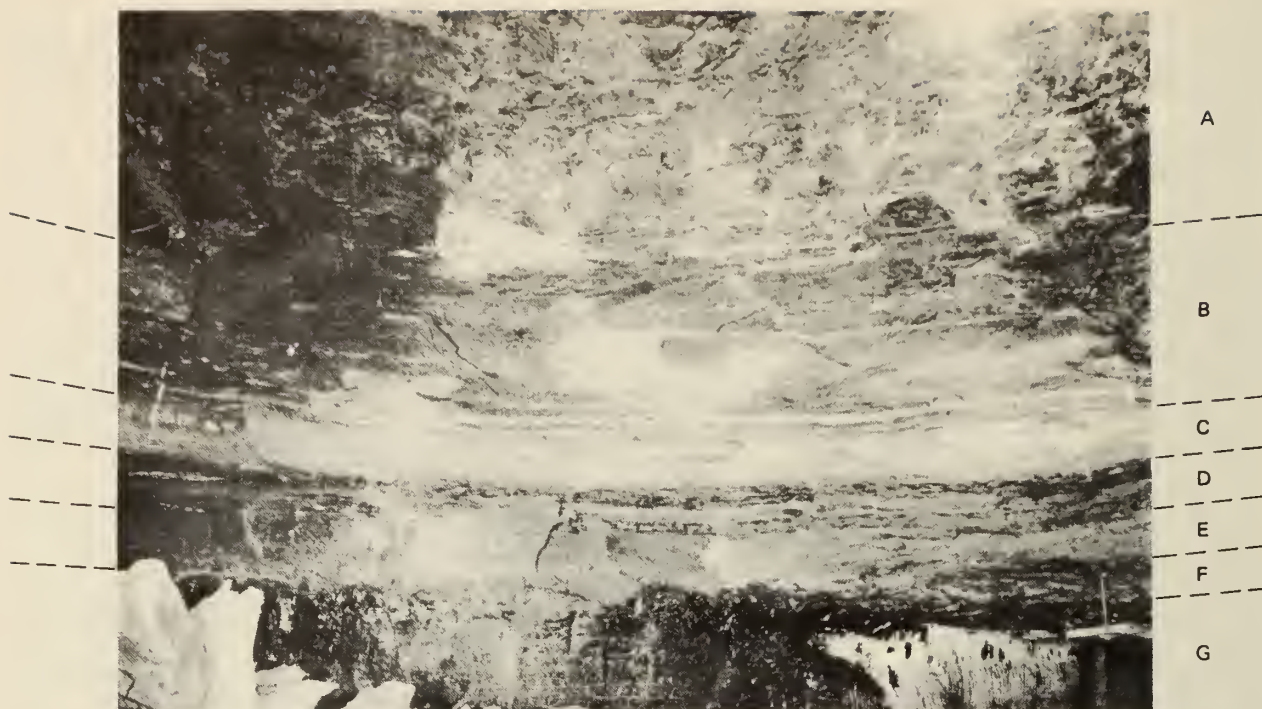


Figure 77. Conant Limestone (*center*) with characteristic dark-brown dolomitic limestone concretions, which show numerous white calcite-filled cracks. Limestone about 1.5 feet thick. Section in photo shows: Lawson Shale, (A) mottled greenish upper portion, and (B) dark-gray lower portion, calcareous at the base, (C) Conant Limestone, (D) "Jamestown Coal interval," (E) Brereton Limestone with very irregular base and (F) "clod," no Anna Shale, and (G) Herrin (No. 6) Coal. Location: mine A, west-central Illinois.



Figure 78. Jamestown Coal between well-developed Brereton and Conant Limestones. The "Jamestown Coal interval" is reduced to a few thin partings of dark, very carbonaceous shales and nodular irregular limestone lenses. Note the dark-brown dolomitic concretionary lenses (A), which are characteristic of the Conant Limestone. The Lawson Shale (top of photo) is exceptionally thin (2 feet; 0.6 m) at this location and is intensively mottled. Location: mine A, west-central Illinois.

and sandstone. In some places, thin stray coal beds are present. Locally the older strata including the Herrin (No. 6) Coal have been eroded, and a channel sandstone (Anvil Rock) is found in their place (fig. 6).

In southwestern Illinois, on the Western Shelf, the interval is much thinner, 10 to 30 feet (3 to 9 m) than in the Fairfield Basin, for instance, and is composed of different rocks. In one part of mine E, the shale is dark gray to black, poorly bedded, calcareous and may contain concretions similar to but smaller than those in the Anna Shale. Elsewhere in the same mine the shale is weak, soft, and greenish gray. Transitions between these two extremes are common.

Shales of this interval are abundantly exposed in mine A, where they range in thickness from 2 to 15 feet (0.5 to 4.5 m). Colors of the shales vary from light through dark greenish-gray to nearly black, and are often mottled (figs. 79 and 80). They may be calcareous in places, grading almost into a solid limestone, and may contain limestone nodules or concretions, especially in the upper part of the unit. The shales are normally poorly bedded, weak, and dissected by numerous minor shear planes and fractures.

The shales appear to be thick where the underlying units are thin. Where the shales overlies thick Brereton Limestone, they are generally light grayish-green, heavily mottled, and very soft, almost like a claystone. This has been recognized along the major faults in study area 1, where the unit is as thin as two feet (60 cm). Where the shales overlies thin limestone, they are normally thicker and can be mapped as two distinct units. The lower is firm, fairly well bedded, dark gray to black, and may contain small marine fossils. Its appearance is similar to that of the upper part of the Anna Shale at mine A. In some places the lower shale horizon is very calcareous, almost a limestone, and contains a few limestone concretions similar to those in the Anna Shale. The upper shale unit is soft, greenish, and heavily mottled. The contact between the two units is typically sharp but very irregular, with fingers of mottled shale up to a foot wide extending deep into the lower layer (figs. 79 and 88). In some areas the shale appears to be dark gray when fresh, and mottled after exposure to moist mine air. Elsewhere mottling is observed in freshly cut rock.

The Lawson Shale contains abundant fractures, surrounded by mottled light-green zones. These mottled zones make the contact between upper and lower layers irregular. The fractures are normally close to vertical, and are oriented randomly, although in a few places preferred trends may occur. We believe that these cracks and fissures are probably syneresis cracks. Whenever these gray shales are exposed by failure of underlying strata, they fall readily. The falls may dome out in shale or extend upward to the base of the Bankston Fork Limestone. The shales seldom can support their own weight or provide proper anchoring for roof bolts. Conventional roof-bolt penetration into the shales may additionally contribute to failure because the bolt holes allow moisture to attack and weaken the rock, except where the base of the shales is very hard and calcareous. Resin bolts, which seal the bolt hole from the mine air, appear to be better. An alternative plan is to use long bolts, anchor them in the Bankston Fork Limestone, and seal the bolt holes from moisture.

In a small area of mine A outside the main study areas, the Lawson Shale apparently forms the immediate roof. Fortunately, the total thickness of shale

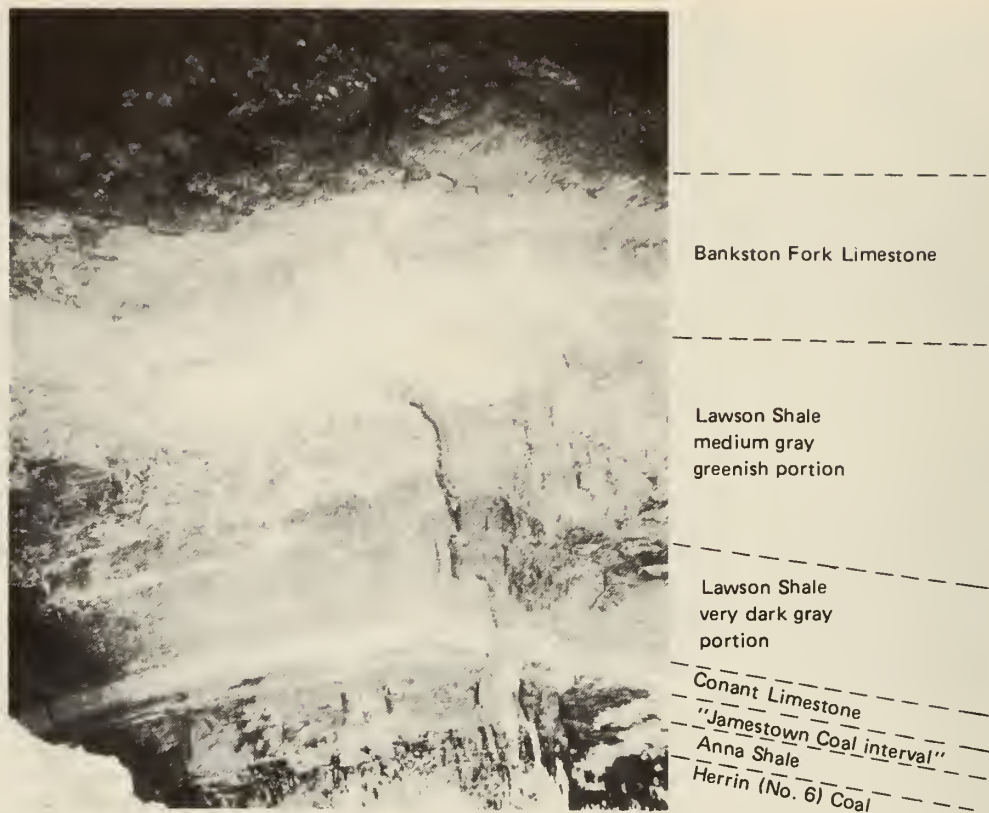


Figure 79. Lawson Shale. Two distinct horizons can be mapped: a lower part very dark gray to almost black shale that is very calcareous in places and contains concretions (left side of photo), and an upper part abundantly mottled soft greenish medium-gray shale with numerous syneresis cracks. Location: mine A, west-central Illinois.

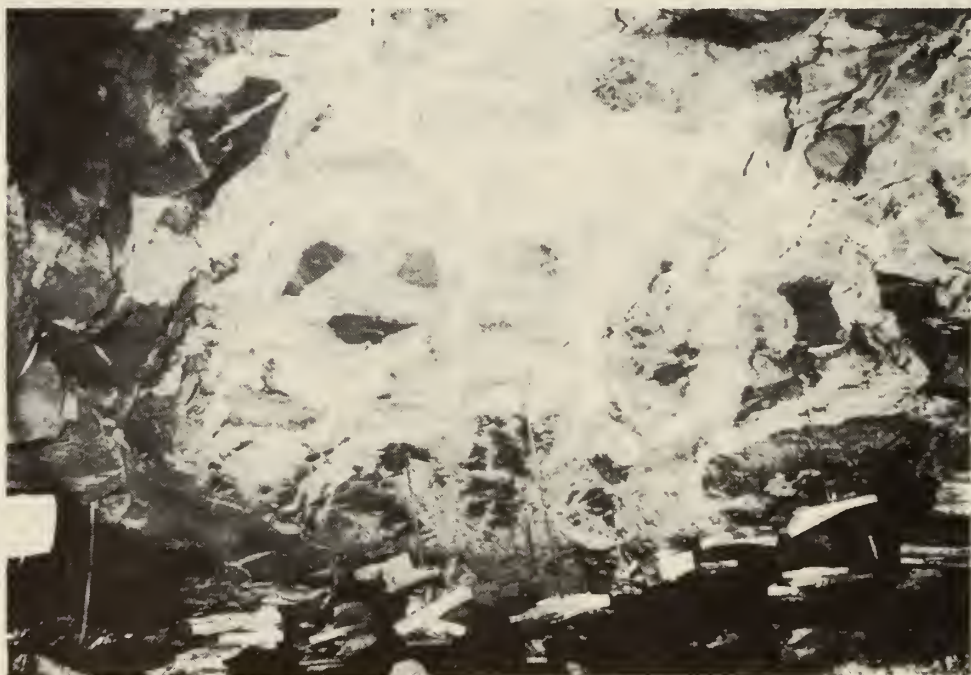


Figure 80. Mottled shale with syneresis cracks in greenish medium-gray shale, above very dark gray shale, probably Lawson Shale (with syneresis cracks) above Anna Shale. Note roof bolts hang out bare; the soft shales have fallen because of moisture slaking; in the center of roof fall, bolt anchors even have fallen out. Location: mine F in east-central Illinois.

is not more than five feet (1.5 m), and high falls do not occur; however, continuous slabbing and shallow roof falls loosen the roof bolts. In a mine in Macoupin County, the Lawson Shale lies directly upon the coal and its thickness is greater than in mine A. Roof falls accordingly are also much higher. Conditions here appear equivalent to those in mine F in east-central Illinois and somewhat similar to mines with gray shale-black shale-limestone transitional roofs.

Mine F, now abandoned, presented an unusual roof sequence (fig. 81). The immediate roof is one to four feet (0.3 to 1.2 m) of very dark gray shale, which resembled part of the Anna Shale but appeared softer and not very fissile. This is overlain by six to ten feet (1.8 to 3 m) of greenish, mottled shale like the upper part of the Lawson Shale at mine A. The contact at places is sharp but more commonly is gradational. The dark shale frequently contains concretions, and the mottled shale is heavily affected by syneresis cracks. Both units are prone to slaking on contact with the air.

Two stratigraphic interpretations are possible. Either the very dark gray shale is of the Anna Shale, or the entire sequence is Lawson Shale. Then the Lawson Shale would consist of a lower dark and an upper mottled shale as at mine A. We interpret the units to be the Lawson Shale, and not Anna Shale, because the dark-gray shale at the bottom is not fissile and is water-reactive in contrast to Anna Shale in other mines and because the contact between the two shale types is often gradational.

The Anvil Rock Sandstone is intimately associated with the Lawson Shale. The Lawson Shale and Anvil Rock Sandstone grade vertically and laterally into one another, more like two different facies than two distinct stratigraphic members. In many parts of the Illinois Basin the shale coarsens upward and frequently has been found capped by a sheet sandstone. From this level, channels, which may cut down to and locally even through the Herrin (No. 6) Coal, have formed. Some of the mines with black shale-limestone roofs have encountered Anvil Rock Sandstone in both the channel phase and the sheet phase. The problems associated with the Anvil Rock Sandstone are water influx and roof instability; however, none of our study areas contained any Anvil Rock channels or sheet sandstones.

Strata of the Bankston Fork Limestone Member

Rocks of the Bankston Fork Limestone, including the various limestones and the interbedded calcareous shales, have not been studied in great detail. The facies and structures of the Bankston Fork Limestone are best exposed in strip mines of southern Illinois. As in mine E, the thick-bedded limestone benches vary from a pure white, almost lithographic limestone to masses of irregular lenses or nodules in calcareous shale matrix and from one bench of limestone into three benches over short distances (figs. 63 and 82).

In mine F of east-central Illinois, the limestone formed the "caprock" of roof falls, 8 to 15 feet (2.4 to 4.5 m) above the top of the coal. In most places only the nodular, irregular base is visible. The entire Bankston Fork Limestone is exposed in the slope entrance, where it consists of two 3- to 4-foot benches of limestone parted by calcareous shale. Drill cores in Vermilion County reveal a complex and variable Bankston Fork Limestone that reaches 20 feet (6 m) in thickness in many places.



Figure 81. Unusual roof sequence above the Herrin (No. 6) Coal up into the Lawson Shale. Soft black shale overlying the coal (which is rock dusted); sharp contact to soft, medium-dark-gray shale, which is itself subjacent to an intensively altered very soft, greenish, medium- to light-gray shale with syneresis cracks. There is no proof whether the black shale is of the Anna Shale or of the lower portion of the Lawson Shale. Location; mine F in east-central Illinois.

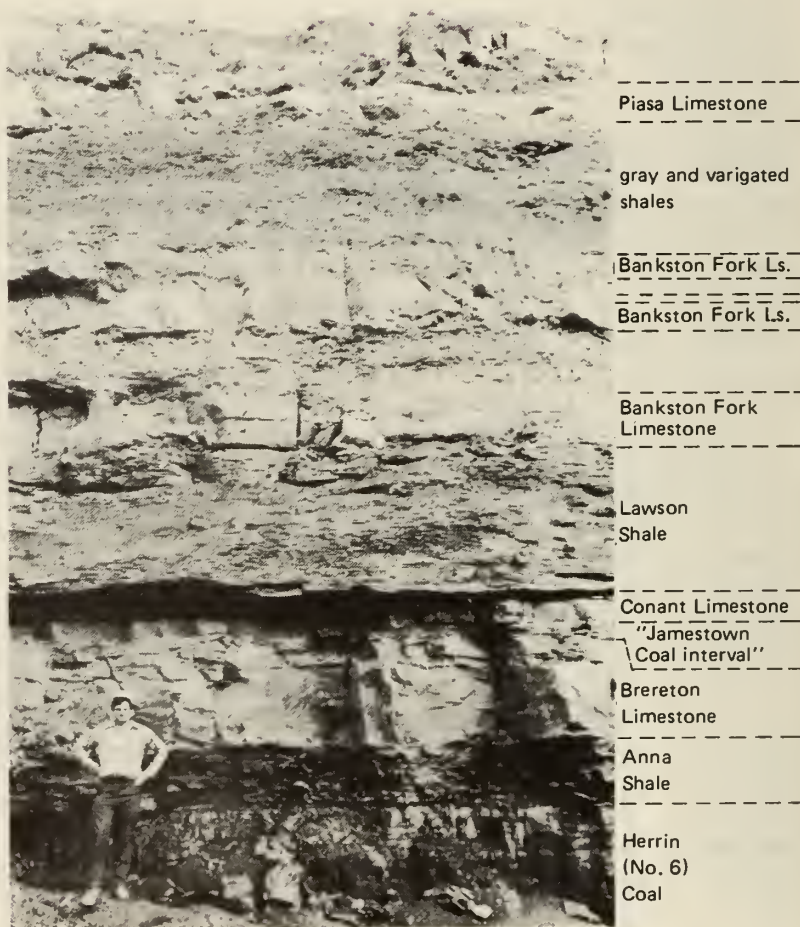


Figure 82. Cross section of black shale-limestone roof sequence from above the Piasa Limestone into the Herrin (No. 6) Coal. (Location: highwall of Mine E, southwestern Illinois.)

In mine A, the limestone of the Bankston Fork performs very similarly. Its base generally forms the top of the highest falls. The thickness of the Bankston Fork may reach 10 feet (3 m), and its base normally lies 10 to 20 feet above the top of the Herrin (No. 6) Coal. In the area where the Lawson Shale forms the immediate roof, mentioned above, the base of the Bankston Fork Limestone lies within five feet of the coal. The Bankston Fork Limestone consists of fine-grained, reddish, greenish, brownish, or gray, argillaceous, somewhat bulky to nodular limestones with thick interbedded layers or partings of greenish mottled calcareous shales. In many high falls, a lower bench of limestone about a half foot thick is topped by a thin shale parting, which is overlain by the flat, unbroken base of the main limestone bench. The same pattern is shown in many cores from the area.

Strata above the Bankston Fork Limestone were observed only in strip mines and at a few major faults and in three or four roof falls in mine A. Although rock units above the Bankston Fork through the Piasa Limestone were included in the portion mapped with the computer, we found no visible evidence that rock units above the Bankston Fork Limestone contribute to or cause roof falls.

STRUCTURES AND DEFORMATIONAL FEATURES IN BLACK SHALE-LIMESTONE ROOF AREAS

Structures and deformational features in black shale-limestone roof areas will be described with reference to the genetic terms syngenetic, diagenetic, or epigenetic, as were the gray shale roof areas. Dividing the discussion of the structural features of the roof strata into these various sections and drawing limits may be somewhat artificial, because the formation and deformation of geologic bodies is continuous.

Depositional Structures (syngenetic structural features)

Distribution, shape, and boundaries of rock bodies of the Anna Shale and the Brereton Limestone Members. Rock bodies and their distributions, shapes, textures, and boundaries provide a structural framework for subsequent deformations, even including those that take place after, or as a result of, mining. The distribution and setting of the wide, thin, disclike lenses of the Anna Shale in mine A are described as prominent examples. Before our investigations and mapping, the Anna Shale had been thought to be a fairly uniform sheet of black fissile shale over almost all of the Illinois Basin Coal Field. It has been demonstrated, however, that the Anna Shale and the Brereton Limestone occur in large lenses or pods of variable and uneven shape and distribution. No specific pattern or preferred orientation was discovered.

The distribution of the Anna Shale is especially significant in west-central Illinois and determines the irregular channellike pattern of the next younger rock member, the Brereton Limestone, which changes in thickness even more abruptly than the underlying shale. The unevenness of distribution of the Anna Shale seems to prevail over large areas of the black shale-limestone roof type. Studies at mine E (strip mine) and other mines show similar patterns, and a regional computer map based on drill records confirms the patchy and podlike distribution of the shale in much of the Illinois Basin Coal Field (fig. 83). The computer maps (figs. 83-85) are more generalized and possibly less accurate than the geologic underground maps, because the accuracy of a computer map depends to a great extent on the amount and distribution of data points, on the distance between data points, the grid size, and the search distance, and because interpolation near the edges of the maps is not always completed accurately by the computer.

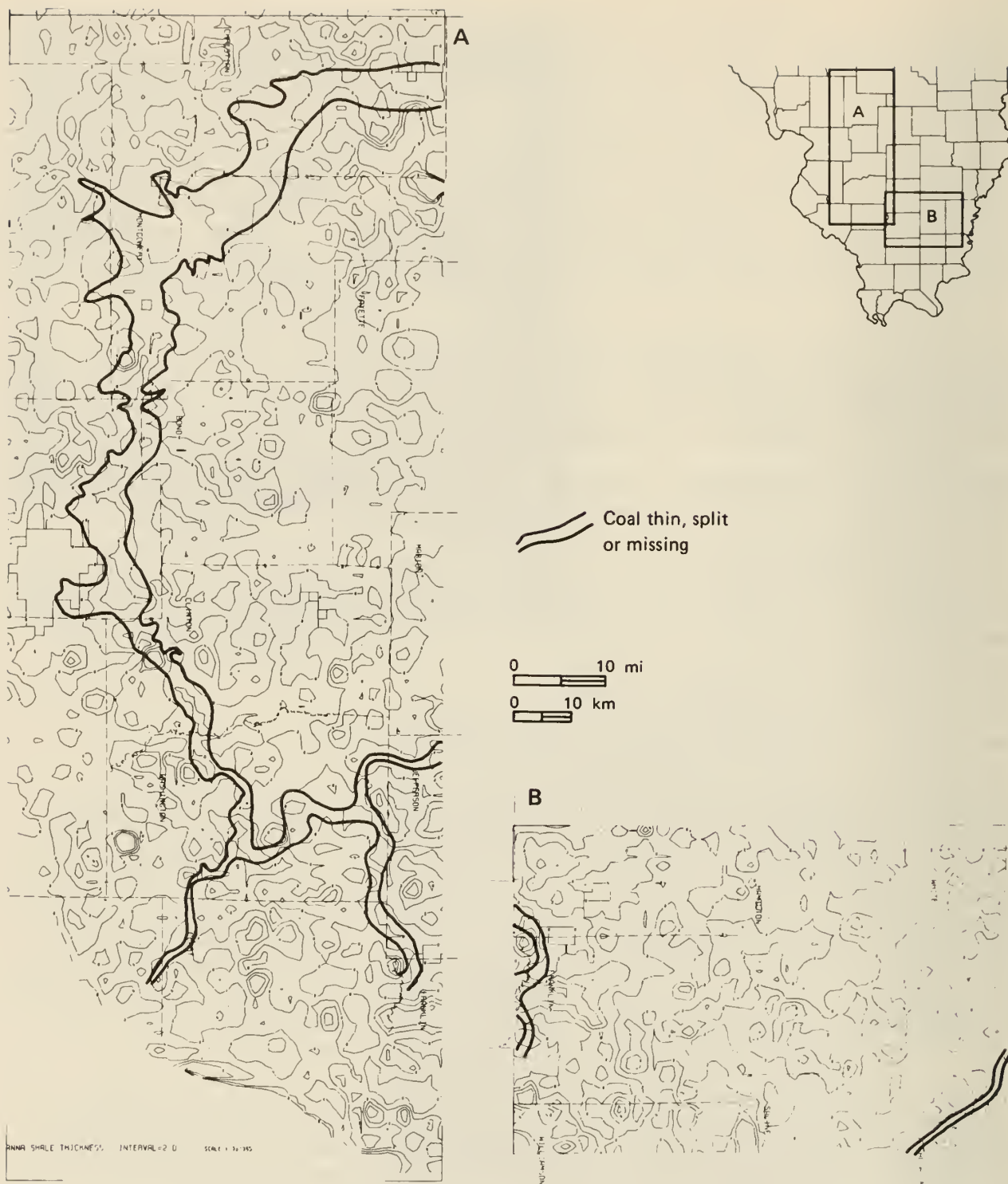


Figure 83. Thickness trends of the Anna Shale Member, southwestern Illinois. Highest contour allowed: 6 feet (1.8 m) thickness. Contour interval: 2 feet. The Anna Shale may reach 6 feet in thickness, but is generally less than 3 feet thick. It is lenticular and patchy throughout the area just as it was observed and mapped in mines A and E, where Anna Shale lenses are often only a few hundred feet in diameter. No apparent pattern or a preferred orientation of Anna Shale lenses has been found, although there is a general trend of decreasing thickness toward the Walshville channel. The Walshville channel and the zone where the Anna Shale is mapped as being absent form a rough semicircle in southern and south-central Illinois. The reciprocal relationship between thickness of the Anna Shale Member and the overlying Breerton Limestone Member as evidenced from detailed studies in mine A is obscured in figures 83 and 84, possibly by the dominance of the regional picture, which shows more dependence on the Energy Shale distribution and the Walshville channel. Greater data-point density was used to determine the location of the Walshville channel.

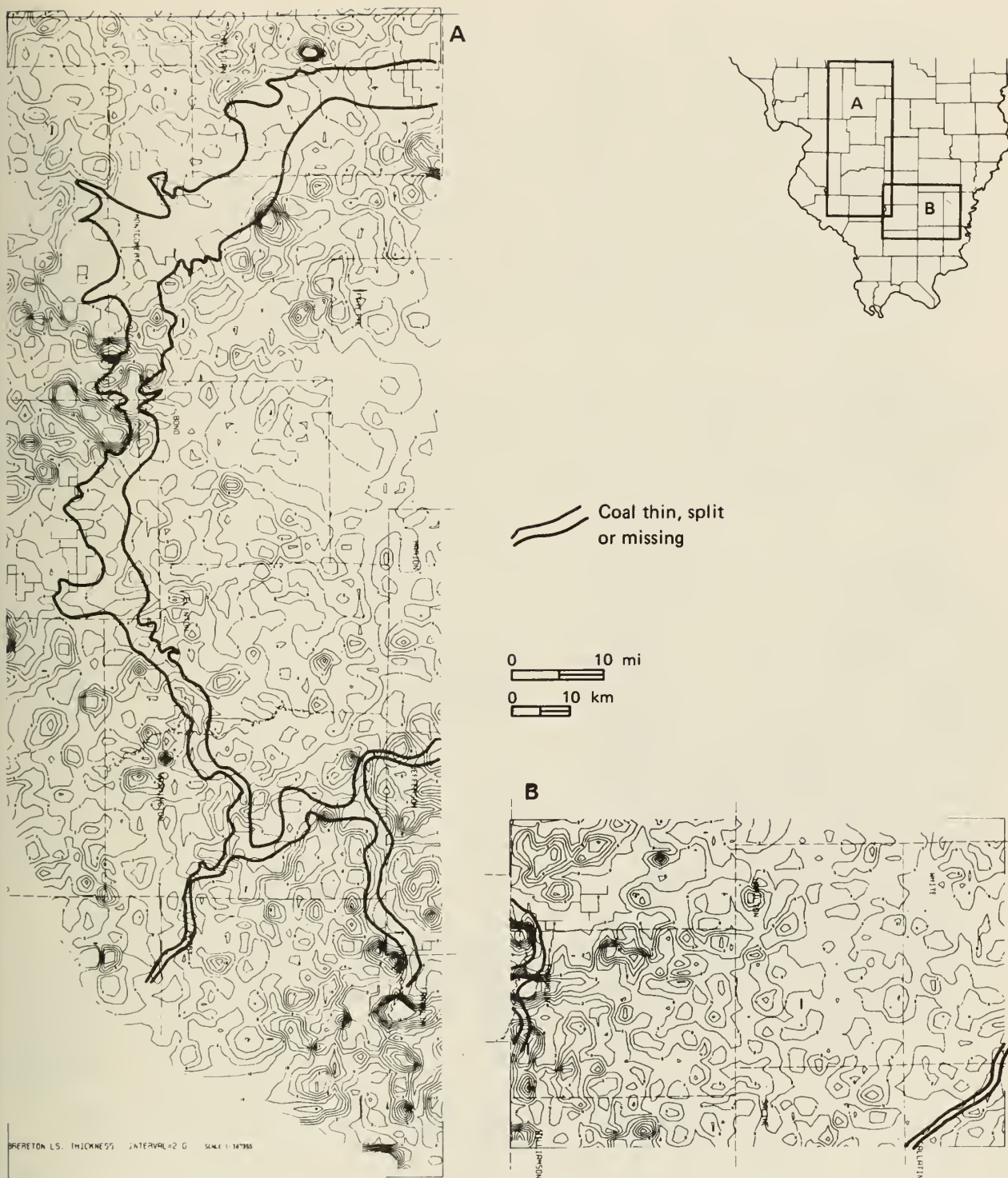


Figure 84. Thickness trends of the Brereton Limestone Member, southern and southwestern Illinois. Highest contour allowed: 16 feet (4.9 m) thickness. Contour interval: 2 feet. The Brereton Limestone may reach 20 feet (6 m) in thickness, but is generally less than 6 feet (1.8 m). It is lenticular and patchy, but overall more pod-shaped and continuous throughout the area, as found in mine A and observed in other mines. Detailed mapping revealed that patches and linear troughs of Brereton Limestone are commonly only a few hundred feet wide. East of the semicircle, framed by the Walshville channel and the zone where the Brereton Limestone is absent, the thickness of the Brereton Limestone generally ranges from 0 to 6 feet (1.8 m), with extremes going up to 14 feet (4.2 m) near the channel. West of the same semicircle, the Brereton Limestone is generally thicker and more consistently present, ranging from 2 to 10 feet, with extremes as thick as 20 feet of limestone. No apparent pattern or preferred orientation of the Brereton Limestone patches has been found. A general trend of increasing thickness toward the channel and sudden rapid decreasing thickness within the channel zone seems to be apparent. Greater data-point density was used to determine the location of the Walshville channel.

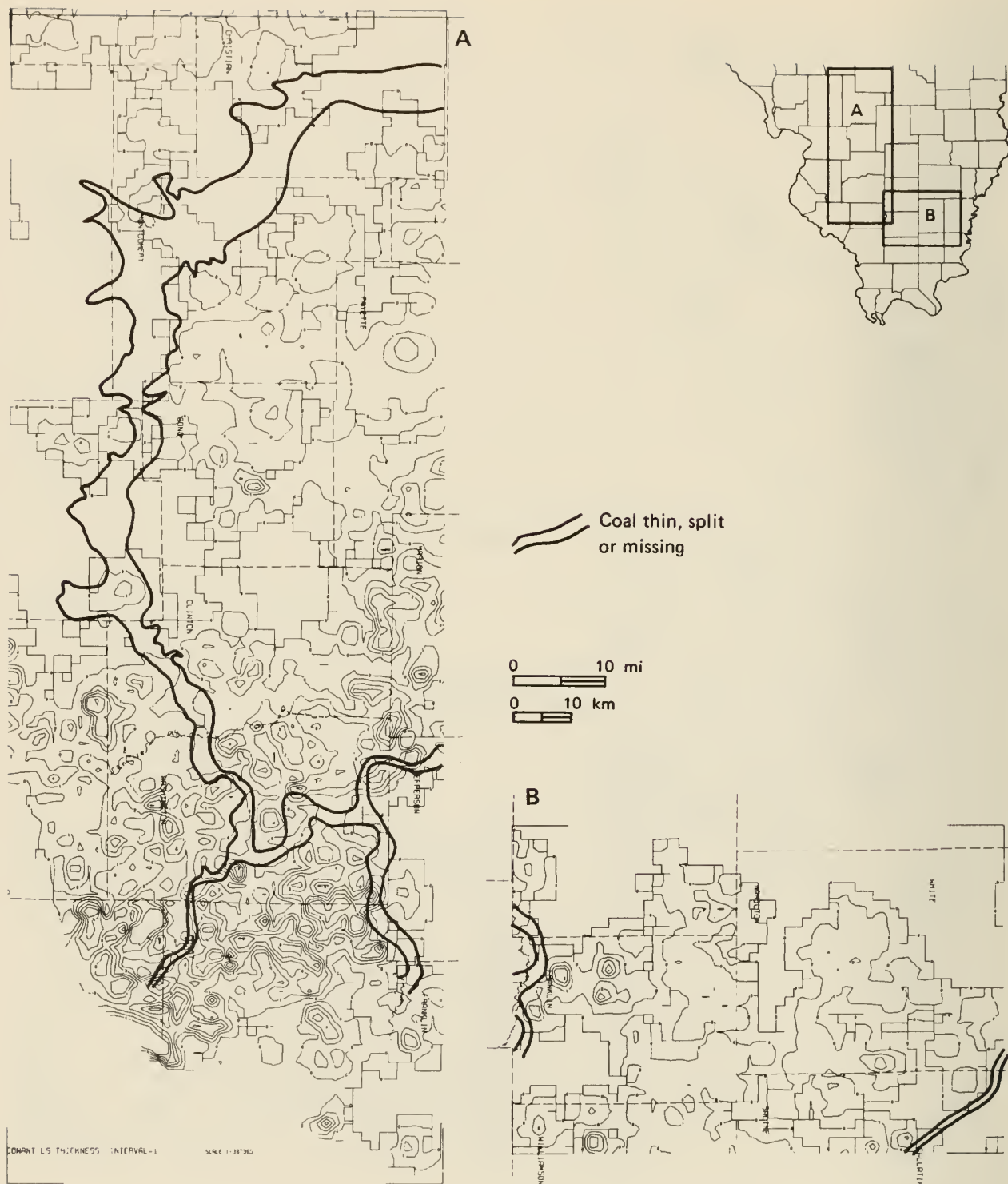


Figure 85. Thickness trends of the Conant Limestone Member, southwestern Illinois. Highest contour allowed: 5 feet (1.5 m); contour interval: 1 foot. The Conant Limestone is generally thin and may reach 4 feet (1.2 m), but commonly is less than 1 foot (0.3 m) thick. It is recognized in most of western and southwestern Illinois, south of the Sangamon Arch and west of the Du Quoin Monocline. The lenticular pattern of the Conant Limestone is similar to that of the Brereton Limestone. The pattern, however, shows no relationship to the Walshville channel at the top of the coal. This map must be used cautiously, because the spacing of datum points in relation to the thickness of the Conant Limestone produces statistically valid distribution patterns only where the Conant Limestone exceeds its normal thickness. Greater data-point density was used to determine the location of the Walshville channel.

Bedding, concretions, and small irregularities. In addition to the distribution of facies, lithology, and the shape and boundaries of rock bodies, all mappable structures and small-scale irregularities in the Herrin (No. 6) Coal roof were mapped. Of those already described in previous chapters, several of major significance to roof instabilities are mentioned again here. Bedding plane separation together with separation along joints in the black fissile shales contributes to intensive slabbing in areas of black shale roof. Concretions, particularly "Anna concretions" (figs. 67-69), are a significant hazard for miners. Although they were found locally in clusters, no pattern in lateral distribution could be determined. The concretions are surrounded by slickensided and highly polished surfaces, and by radially oriented joints and cleats around the concretions which developed from differential compaction between concretions and surrounding sediment.

"Washouts" and bodies of bastard limestone are of lesser importance to roof performance because of their local distribution. Irregular limestone protrusions called limestone "bosses" (fig. 86), which are common in some mines, are not threats to roof stability but may cause excessive wear on continuous miners, as do very local bodies of calcareous or pyritic spherulitic accumulations, including coal balls in the top layers of the coal.

Syneresis cracks. Syneresis cracks are similar to dessication cracks, but they form under a cover of water, particularly in clays and lithographic lime muds. They result from a coagulation of the solid particles in the still unconsolidated sediment with a simultaneous expulsion of water. Syneresis is particularly well known in gels and gellike materials. In Pennsylvanian shale, mudstone and claystone syneresis cracks are common. In some places, the cracks are filled with siderite, dolomite, and calcite in various proportions (figs. 87 and 88). In other cases, the cracks and fissures remained unfilled and allowed circulation of solutions within them. This circulation, possibly with aid of bacteria, discolored zones of clays adjacent to such fissures to a light pale gray. Gray shales, in particular those of the Lawson Shale, are in places heavily affected by syneresis and, because of the discoloration, have a mottled appearance (figs. 80, 81, 87, and 88).

Mottled shales are probably the weakest strata of the roof sequence above the Herrin (No. 6) Coal. Where mottled shales lie close to the coal because older strata above the coal are thin or missing, roof failures are common. Standard roof bolts and anchors may easily strip the bolt hole without anchoring.

Clay-dike faults, clastic dikes and associated features (diagenetic structural features)

While sediments are being accumulated on the surface, syngenetic structures are formed. As overburden and load increase with greater depth, diagenetic structures develop, and the syngenetic structures begin to be deformed. Chemical processes continue. Oxidation, however, decreases, whereas reduction and cementation increase. Textures and structures of rocks as they form are controlled or altered by mechanical action—mainly compaction, reduction of pore volume, and increase of pore pressure. As rock bodies contract or dilate, diagenetic structural features develop. In black shale-limestone roof rock the most significant diagenetic deformational elements are clay-dike faults and clay dikes.

Clastic dikes are dike-shaped intrusions of extraneous sediments from above (or below) into the containing sediment. Clay dikes, also called clay



Figure 86. Large limestone "boss" above Herrin (No. 6) Coal has deformed and truncated the top beds of the coal seam. Anna Shale is absent, and the Brereton Limestone ("boss") directly overlies the coal. Location: west-central Illinois, mine S.



Figure 87. Syneresis cracks and mottled shale a few feet above Herrin (No. 6) Coal. Mottled shales are very weak strata in which standard roof bolts cannot be anchored easily. Original bolts had been set into the mottled shale, but were pulled out as the roof failed. Location: mine E in southwestern Illinois.

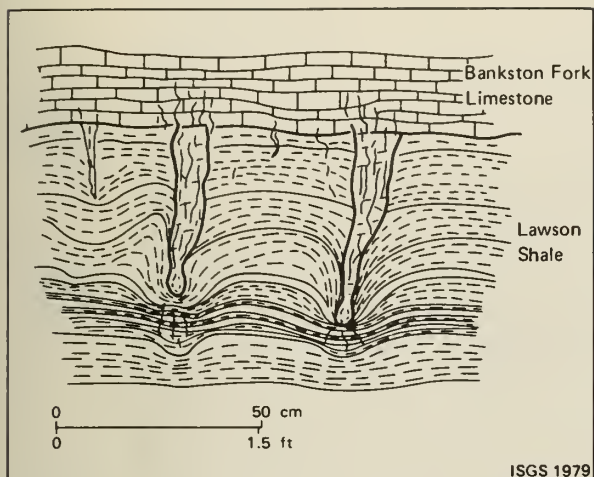


Figure 88. Desiccation fractures or, more probably, syneresis cracks in gray shales of the Herrin (No. 6) Coal roof strata. Fractures are filled with calcareous material and calcite. Deformation of bedding in shales indicates that fracture filling is penecontemporaneous with, or older than, the entire compaction. Location: Vermilion County, mine F.

veins, are clastic dikes; specifically, they are dikes containing clay or silty clay material in a coal seam. Clay dikes occurring in the Illinois Basin have been described (Damberger, 1970 and 1973); however, no detailed maps or studies of clay dikes and their deformational features as related to significant characteristics of their host rocks have been published. Detailed mapping during our investigation increased our knowledge about these deformational elements considerably.

The principal difference between clay dikes and clay-dike faults is that the clay dikes have a filling. Most of the deformational features that are characteristic of clay dikes are present in and around clay-dike faults. Because of the lack of filling, those features are not always easy to recognize and are frequently overlooked.

Clay dikes and clay-dike faults in coals in Illinois (referred to by miners as "horsebacks") have been reported from the Kewanee and McLeansboro Groups of the Pennsylvanian System.

Clay-dike faults. Clay-dike faults are a special type of fault. They are probably caused by local stress systems that developed during deposition and increased during diagenesis. The major compressive strength was vertical, and stress increased as overburden and pore pressure increased. None of the faults in the seven areas mapped seems to be a tectonic fault, which would be related to a specific tectonic stress field in the Illinois Basin.

The clay-dike faults studied in greatest detail were in mine A, where clay dikes and clay-dike faults are common (figs. 89-94). Every fault in mine A is normal, i.e., the hanging wall is downthrown. Almost all clay-dike faults are low-angle normal faults. Inclination of faults is as low as 15° to 20° , but a dip of 40° to 50° is more common (fig. 95). The faults usually begin as sub-horizontal bedding plane shears in the roof rock above the coal. Their inclination steadily increases downward and steepens rapidly as they extended into the coal seam, where they most commonly terminate as a system of en echelon extension fractures, (figs. 96-101).

The great majority of clay-dike faults have less than 3 feet (0.9 m) of displacement, and many displacements are less than 1 foot. The maximum throw measured in mine A was 18 feet (5.4 m). Usually the greatest displacement is near the top of the coal. As the fault steepens downward the vertical displacement decreases and the horizontal displacement is taken over by the opening of the extension fractures. Because of their shape, these extension fractures are named "goat beards" (figs. 96, 97, 98, 100, and 101). "Goat beards" are defined here as a system of more or less vertical extension frac-

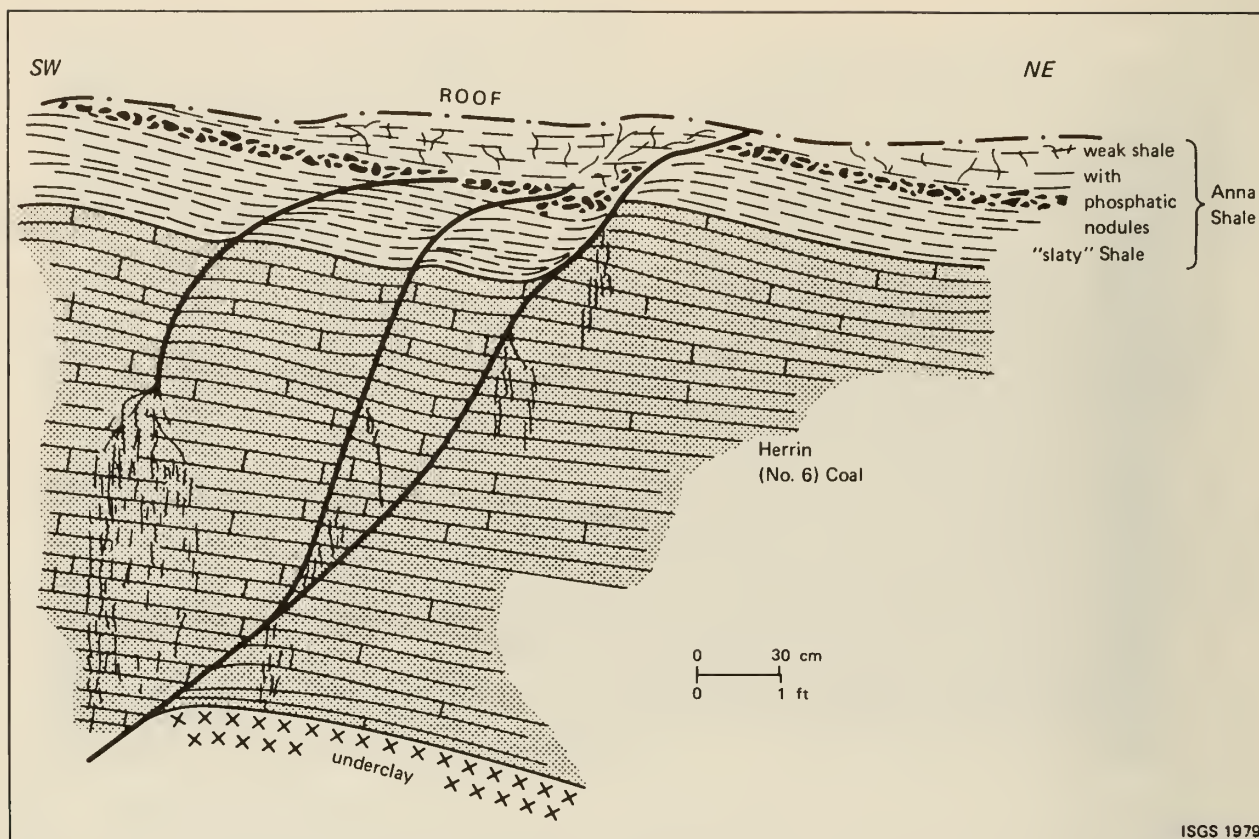


Figure 89. Low-angle normal faults; the main fault cuts Anna Shale, Herrin (No. 6) Coal, and the top of the underclay. Faults steepen downward into the coal. The steepening, slight tilting of faulted blocks, false drag in places, and en echelon extension fractures ("goat beards") strongly suggest that the faults are clay-dike faults. Location: west-central Illinois, mine A.

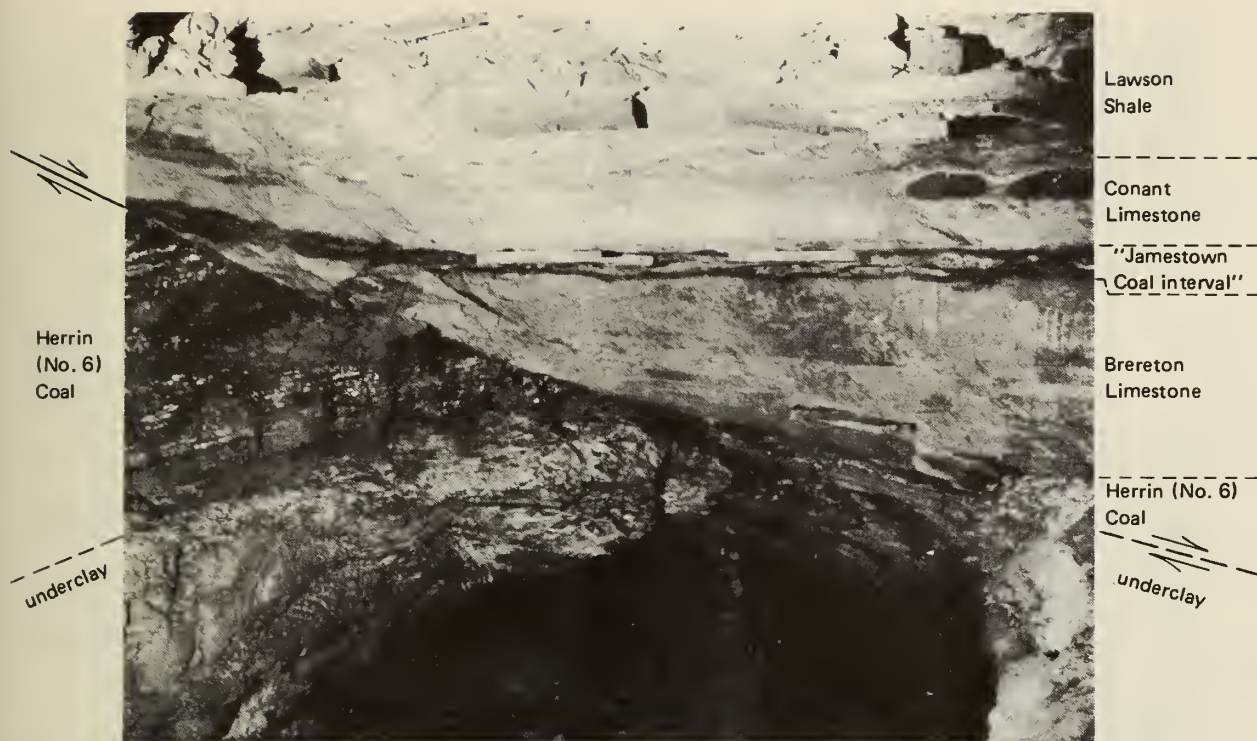


Figure 90. The clay-dike fault shown is a low-angle normal fault ($N 95^{\circ}-115^{\circ} E/35^{\circ}-50^{\circ} SSW$) with six to eight feet of throw. Shales, calcareous strata, and lower portion of Herrin (No. 6) Coal show normal drag. Strata from the underclay of Springfield (No. 5) Coal up to the Bankston Fork Limestone are exposed and truncated. Location: study area 1, mine A, west-central Illinois.

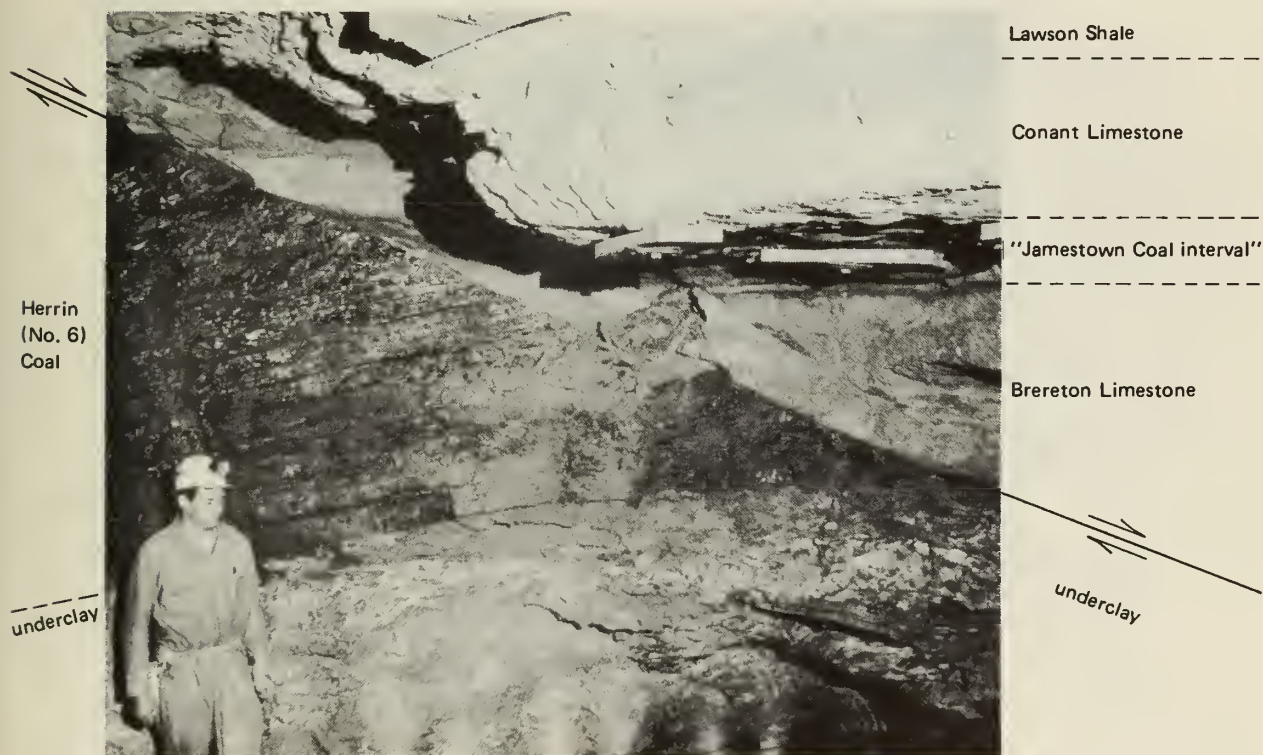


Figure 91. Area shown in figure 90, from a different viewpoint, showing false drag in the upper portion of the coal.

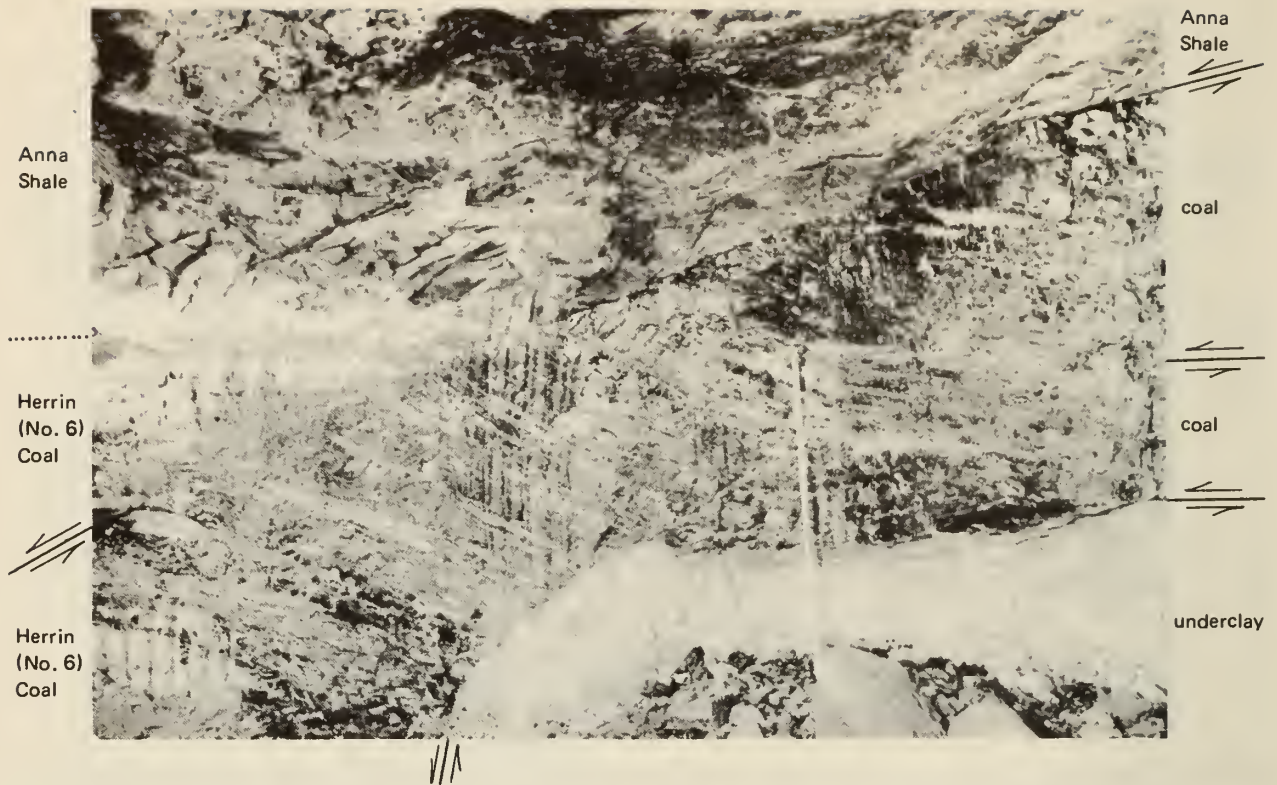


Figure 92. Low-angle clay-dike faults penetrating underclay, Herrin (No. 6) Coal, and Anna Shale. Note tilted block and false drag between the major faults and normal drag, extension, and flow and shear faulting in the Anna Shale. Parallel shearing occurs along shale partings within the coal and on the coal-underclay interface. The white area in the left center is rock dust on the Anna Shale and top coal. Location: study area 1, mine A, west-central Illinois.

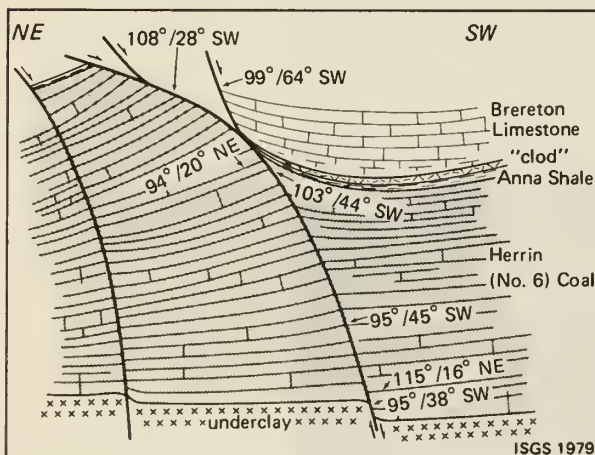


Figure 93. Clay-dike faults cutting through entire coal seam and displacing Brereton Limestone, Anna Shale, Herrin (No. 6) Coal, and underclay. Note normal drag and thinning of Anna Shale and Brereton Limestone strata and false drag in some places of coal. Location: mine A, west-central Illinois.

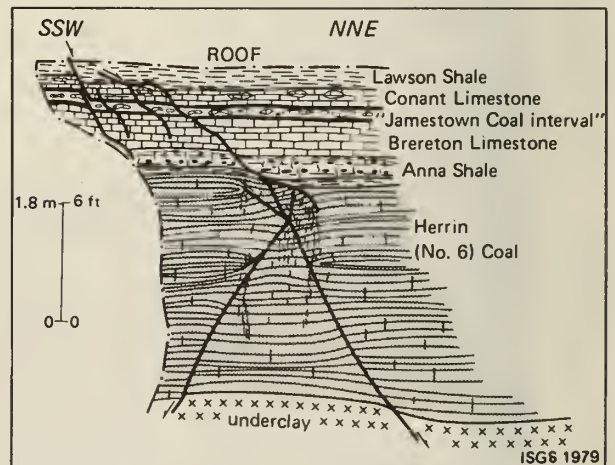


Figure 94. Clay-dike faults dissecting the Herrin (No. 6) Coal and associated rock strata. The faults result not from vertical movements, but mainly from horizontal extension of the strata, as indicated by collapsed graben-like structures in the upper coal benches and rebound horst-like structures in the underclay and lowest coal benches. Note the convergence of the coal bedding in places, the en echelon extension fractures ("goat beards") and the splitting and downward steepening of the faults in the coal seam. Location: mine A, west-central Illinois.

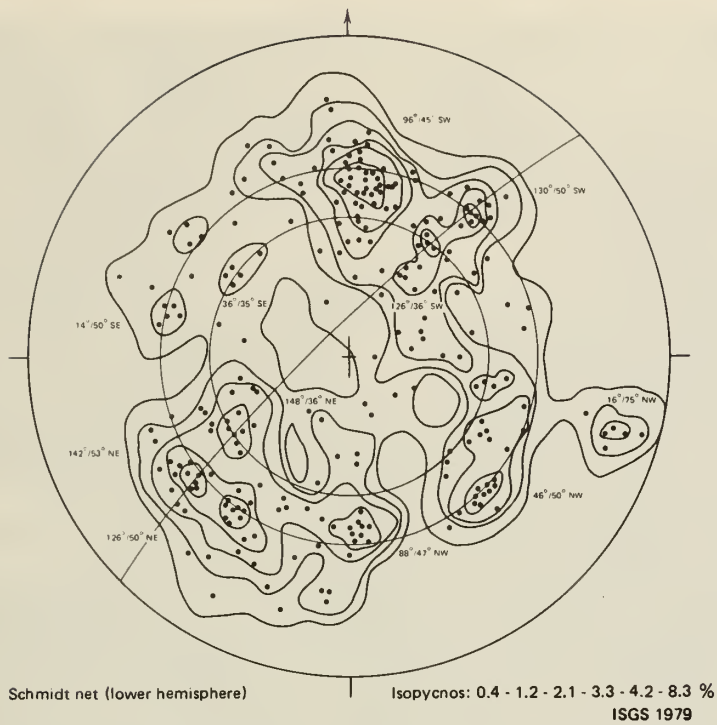


Figure 95. Orientation diagram of 240 poles of clay-dike faults. The distribution pattern displays the low angle of the faults and the preferred orientation within a small circular zone, which indicates the significance of the lateral extension in comparison to vertical movements. Measurements were taken in a randomly selected area of study area 1 in mine A, west-central Illinois, December 1974.

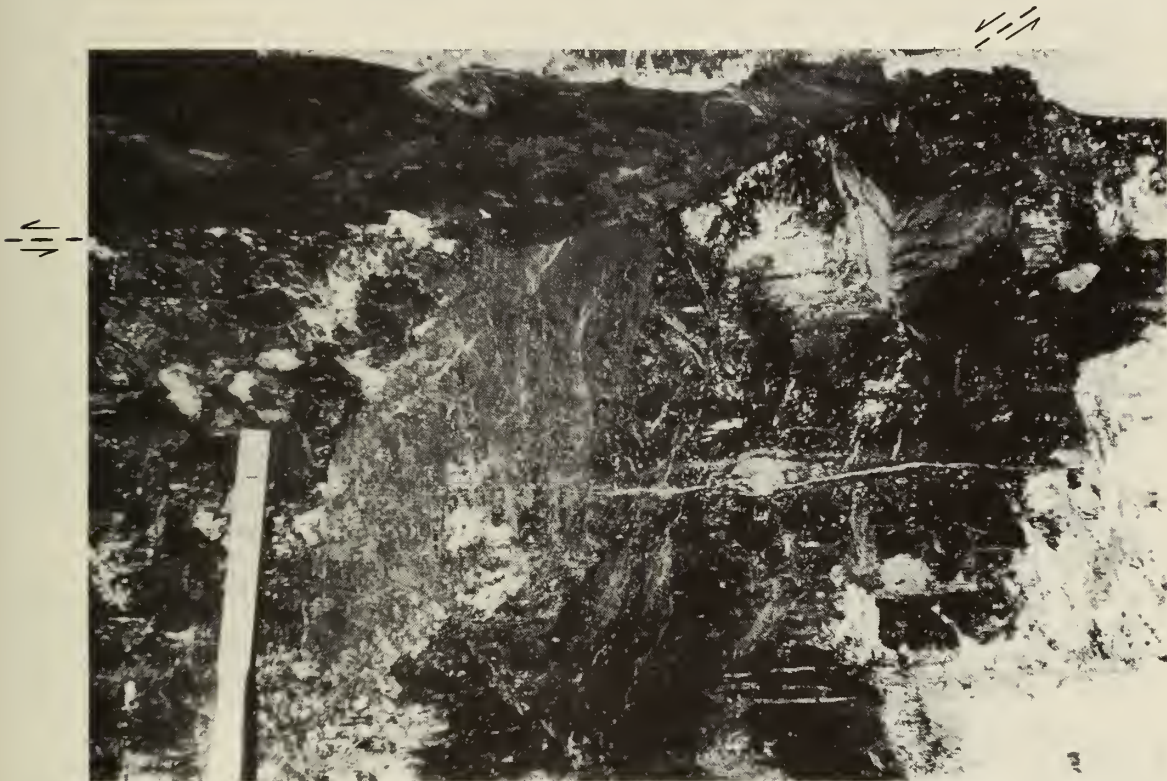


Figure 96. "Goat beards" at lower end of low-angle normal clay-dike fault. Fault penetrates Anna Shale and Herrin (No. 6) Coal, displacing top of coal bed 0.6 feet (0.2 m) downward, but mostly laterally. Lateral extension terminates in the densely spaced extension fractures of the "goat beard."

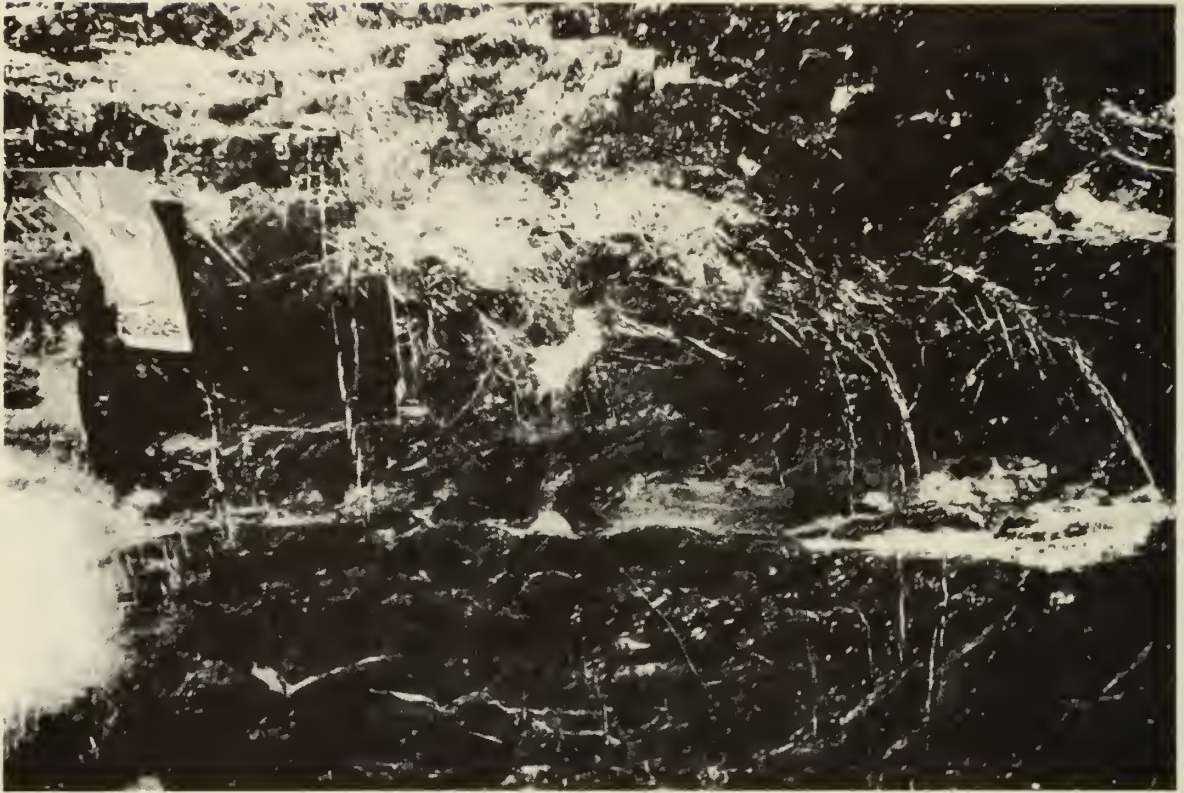


Figure 97. "Goat beards" in coal below zone of clay dikes and clay sills (as in upper left of photo). Note the numerous en echelon extension fractures. Almost all extension fractures are calcite-filled.

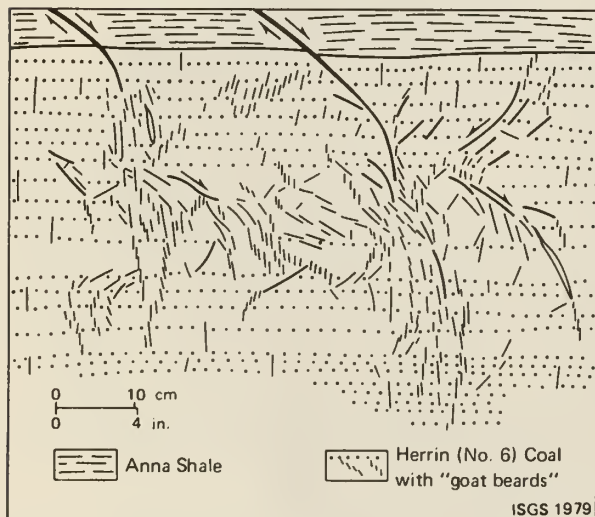


Figure 98. Lower end of two low-angle normal faults (clay-dike). Faults cut Anna Shale and displace top of Herrin (No. 6) Coal, steepen downward into coal, and dissipate in the form of numerous extension fractures, many of which are en echelon "goat beards." Extension of Anna Shale strata results from dip slip along low-angle normal faults. Dilatation of coal seam caused by extension fractures ("goat beards") and some minor low-angle normal faults. Location: mine A, west-central Illinois.

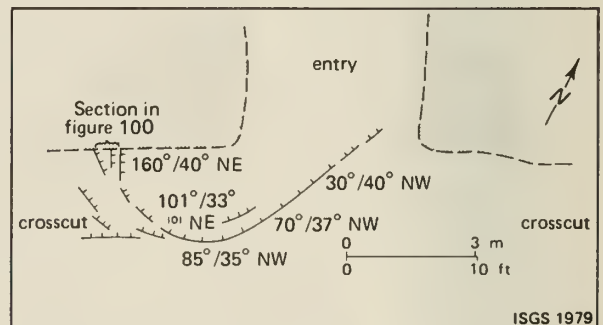


Figure 99. Change of trend of low-angle normal faults on bottom of the Anna Shale (dip direction and downthrown side indicated). Strike and dip data given as azimuthal angle (N over E), inclination angle, and dip direction (e.g., 101/33 NE = N 101° E/33° dip towards NE). This lobate curving (in strike) of low-angle faults can be observed in many places and is related to boundaries of lithologic variations. Location: mine A, west-central Illinois.

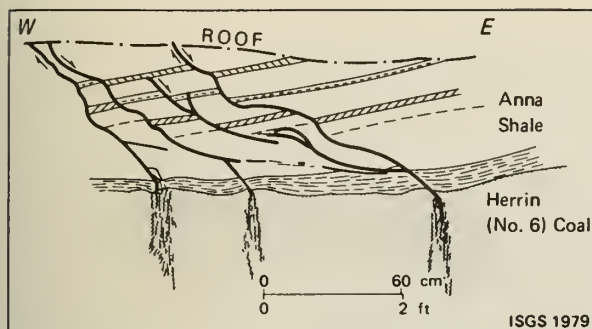


Figure 100. Low-angle normal faults displacing Anna Shale and dissipating in form of "goat beards" (en echelon extension fractures) as they protrude into top of coal seam. While amount of displacement appears to be decreasing downward, thinning (stretching) of Anna Shale layers, particularly the lowermost, fissile portion, shows up significantly. This proves the intense horizontal extension of the strata. Note the antithetic position of bedding and fault surfaces, which result from block tilting during the faulting. Bedding of the Anna Shale is indicated by several different symbols for layers of phosphatic materials, weak medium-dark-gray shale and the fissile ("slaty") black shale in the immediate roof of the coal. Location: mine A, west-central Illinois.

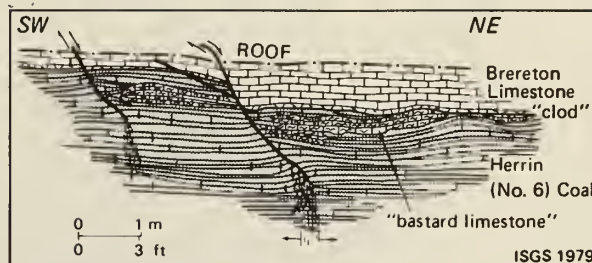


Figure 101. Low-angle normal faults (clay-dike). Faults displace Brereton Limestone and top of Herrin (No. 6) Coal, steepen downward in the coal, and dissipate in form of numerous en echelon extension fractures. In places coal shows false drag. Horizontal extension is achieved by dip slip on faults in the Anna Shale and top coal and mainly by the extension fractures ("goat beards") in the coal seam. Note the displacement of "bastard limestone." Location: mine A, west-central Illinois.

tures in coal which are generally staggered or en echelon. They are usually found at the vertical or almost vertical lower end of a clay-dike fault in the coal. They form narrow zones of fractures that are heavily mineralized with pyrite, calcite, or sphalerite. "Goat beards" are abundant near the top of the coal seam, indicating a small fault or slip in the roof. Where top coal has been left in the entry, the "goat beards" may help to reveal a hazardous roof instability.

Although the faults show vertical displacement, the faulted blocks are not actually downthrown. The blocks appear to be tilted (fig. 92), and the strata display false drag (reverse drag) in many places (fig. 102). Over a larger area in the vicinity of the faults, the faulted strata remain at the same depth (fig. 94, 100, 103, and 104). The lateral or horizontal displacement therefore appears to have much greater importance than the vertical. There are three different expressions of these lateral movements: (1) "goat beards" (extension fractures) in the coal, (2) clay-dike faults and tilted blocks, and (3) parallel shearing along the bedding planes in the roof rock, and in places along clay partings in the coal and at the interface of the coal and underclay.

Clay-dike faults display not only false drag and tilted blocks, but also local convergence of individual beds, particularly toward protrusions from clay dikes and clay sills and toward the rare antithetic minor faults that branch off from major faults (figs. 94 and 104).

Soft-sediment deformation is invariably associated with clay-dike faults. Significant characteristics are thinning of shale layers, flow structures, rotation of concretions, pull-apart and thinning as well as thickening in connection with soft-sediment folding, gradual transitions between flow and flow-angle faults. Different materials may react differently to deformation: some materials flow (plastic deformation) and some fracture and shear

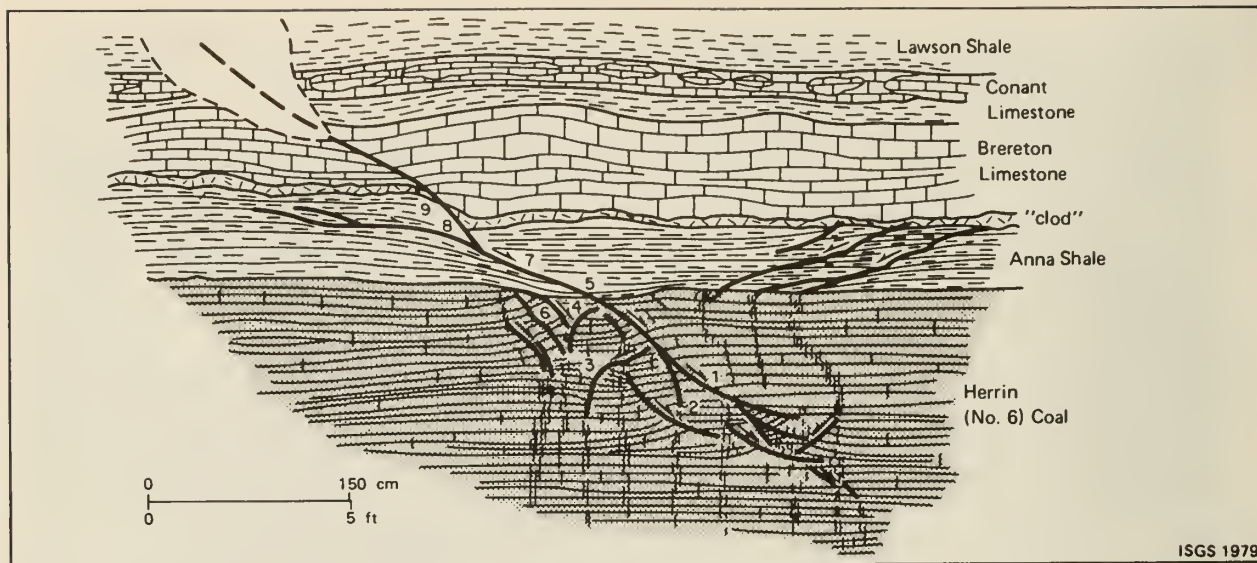


Figure 102. Clay-dike fault penetrating and displacing strata from the Lawson Shale down to the Herrin (No. 6) Coal. Most intensive deformation and displacement has affected the Anna Shale and the upper portion of the Herrin (No. 6) Coal. Lateral thinning (extension) of shales, tilting of coal blocks, false drag, steepening of individual shear planes downward and en echelon extension fractures ("goat beards") in the coal are most common deformational features in this type of late diagenetic or early epigenetic faulting. Rather thin (0.5 cm) clay dikes in places along faults are not shown in the figure. Location: mine E, Western Shelf, southwestern Illinois.

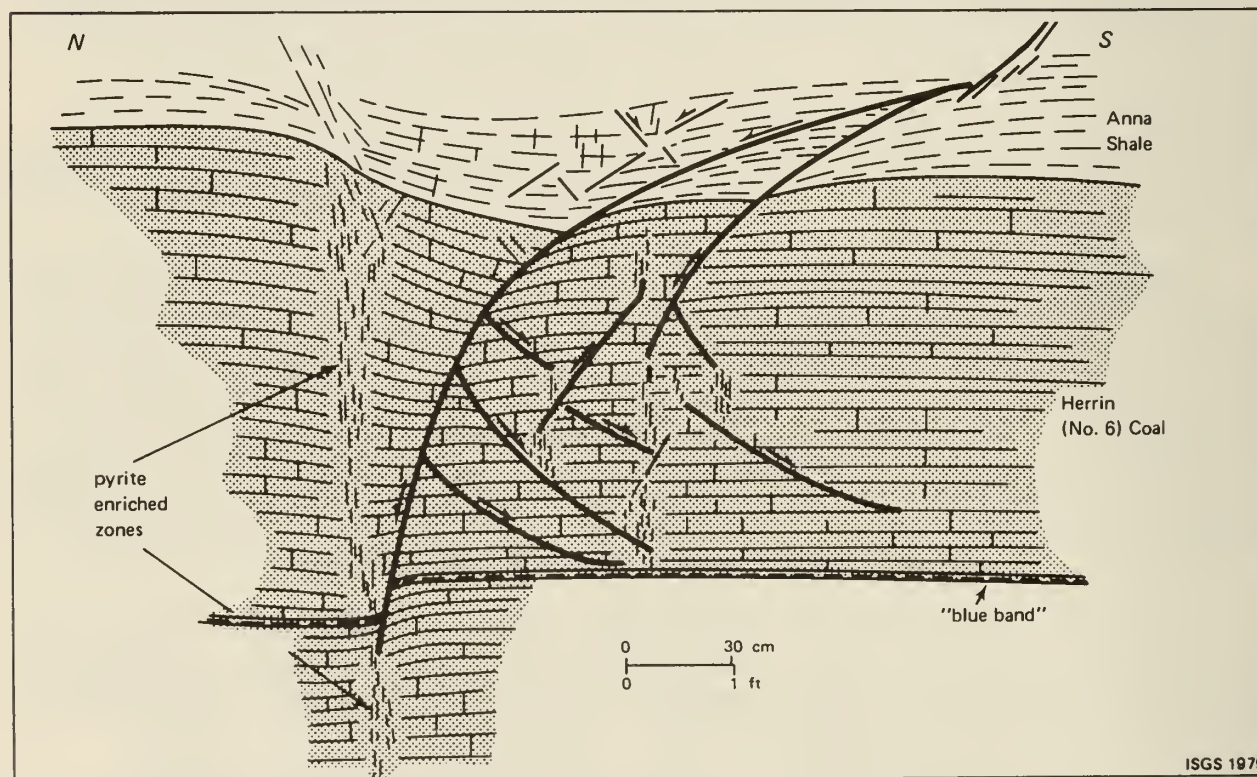


Figure 103. Low-angle normal faults displacing and "stretching" the Herrin (No. 6) Coal and the Anna Shale. Main faults steepen downward and dissipate in the form of en echelon extension fractures ("goat beards"). Most of the slippage along faults and fracturing did not truncate the "blue band," while slippage occurred along the interface of the coal and "blue band." The "blue band" was displaced at an intersection of the major fault, dipping north, and a "goat beard" (pyrite-enriched zones), which may indicate a fault in the roof above. Note both true and false (normal and reverse) drag in the coal layers. Location: mine E, Western Shelf, southwestern Illinois.

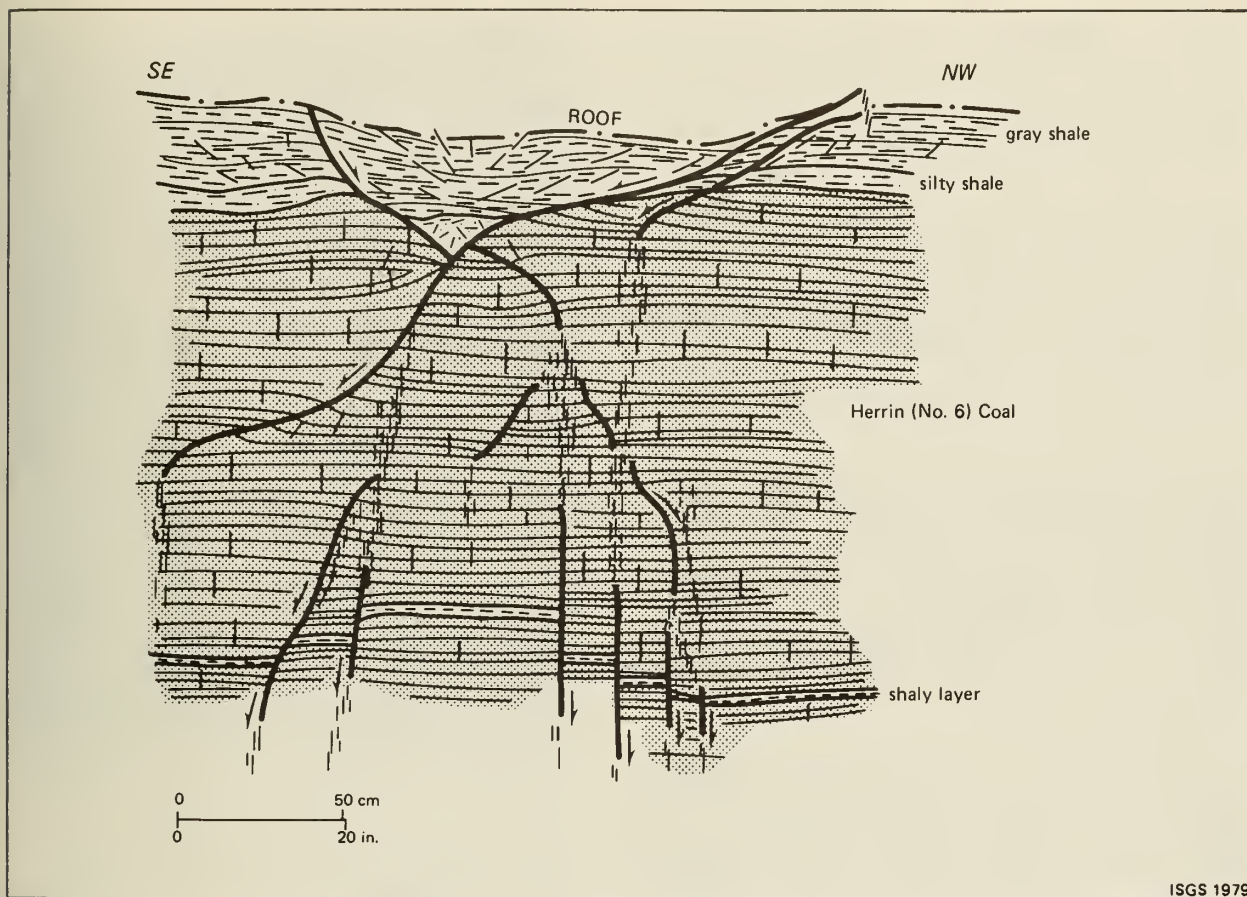


Figure 104. Clay-dike faults forming a graben at the top (note the intensely sheared gray shale) and a horst at the bottom of the Herrin (No. 6) Coal. Low-angle normal faults in shales above the coal steepen downward into the coal and dissipate in the form of en echelon extension fractures ("goat beards"). Farther down in the coal seam faults also form an en echelon pattern and produce a step-faulted horst. Note convergence features of coal beds (upper left area) and false drag. Total deformation is due mainly to horizontal extension with little or no vertical throw of strata. Location: west-central Illinois, mine N.

coal. They form narrow zones of fractures that are heavily mineralized (brittle deformation). All of this is further evidence that the clay-dike faulting occurred before the sediments were fully compacted and lithified. The amount of overburden on the coal at the time probably was on the order of a few tens of feet to about 300 feet (to 100 m). The fault surfaces are rarely planar, but tend to be curved along both strike and dip. The curvature makes it difficult to take representative readings of strike or dip.

Clay-dike faults occur in all roof lithologies, unlike clay dikes, which are concentrated under limestone roof. Like clay dikes, the faults mainly strike more or less parallel to lithologic boundaries (e.g., the Anna Shale-Brereton Limestone) in the roof. Study area 2 in mine A is a clear example of this parallelism. Faults under Anna Shale roof dip toward the center of Anna Shale lenses, and faults under limestone dip toward the cores of the limestone bodies. Near the centers of roof rock bodies, fault trends show less regularity in orientation.

Large clay-dike faults cut across lithologic boundaries rather than running parallel to them. This is displayed along the east edge of study area 2 (fig. 128, p. 128), where the fault has displaced the strata up to 10 feet (3 m). The major fault system in the northern part of study area 1 likewise

crosses lithologic boundaries (fig. 122, p. 116). In both cases the faults cut very thick Brereton Limestone. It is difficult to mine and grade through these large faults, but roof conditions near the faults are good wherever the Brereton Limestone is thick. At the site of maximum displacement the Brereton is 11 feet (3.4 m) thick.

Where clay-dike faults are large or numerous, they cause many roof falls. Examples of the destructive effects of major faults outside areas of thick Brereton Limestone are present in several parts of study area 2. The most complexly faulted area mapped lies in the center of the study area, where several sets of faults converge and make the roof extremely unstable. Only extensive cribbing and timbering has prevented roof collapse elsewhere nearby (fig. 129, p. 131).

Most of the small clay-dike faults and clay dikes are confined to the coal seam and the black shales immediately above. The major faults, on the other hand, extend well below and above the coal seam. In study area 1, the Springfield (No. 5) Coal, about nine feet (3 m) below the Herrin Coal, and the Bankston Fork Limestone, 15 feet (5 m) above the Herrin Coal, were offset by the faults. It was apparent, however, that these major faults also diminish in throw both upward and downward away from the Herrin (No. 6) Coal, as well as along their strike.

Clastic dikes and clay dikes. Clay dikes are fairly common in the Illinois Basin Coal Field, and are found in nearly all major coal seams. They are as abundant in areas of black shale-limestone roof as rolls are in areas of gray shale roof. Clay dikes are also abundant in the Appalachian and other coal fields. They have considerable effect on mining procedures and on roof stability.

In Illinois, the patterns formed by clay dikes vary in different coal seams and regions of the state. Clay dikes are common in the Colchester (No. 2) Coal west of Peoria (fig. 105). Some clay dikes in the Colchester (No. 2) Coal can be traced into narrow vertical fractures or breccia zones that may extend 30 feet or more into the shale above. Clay dikes are especially abundant in the Springfield (No. 5) Coal of west-central and western Illinois (cf. Damberger, 1970 and 1973). The great abundance of clay dikes there forced the closing of some mines. Many of the dikes are nearly vertical and extend from the coal several feet upward into the roof strata, ending in a V-shaped system of slips that extend even higher into the roof sequence (fig. 106). Roof control around clay dikes has been difficult, especially in mines near Springfield, Illinois. Failure typically occurs along the strike of dikes below the



Figure 105. Clay dike in Colchester (No. 2) Coal in a strip mine in northwestern Illinois. Large coal fragments in the clay matrix, the very irregular form, and the steep dip are characteristic of the clay dikes.



Figure 106. Clay dike in Springfield (No. 5) Coal and black or dark-gray shale. Clay filling, brecciated material, and matrix are concentrated within the coal seam and the lower portion of the black roof shale. Farther upward, the dike splits into numerous thin branches and the dike zone spreads out laterally. The filling thins as the dike approaches the St. David Limestone. The side branches grade into slickensided shear planes. In the limestone, the branches of the dike rejoin, and a thicker clay dike is exposed. The cross section has a funnel shape, narrow at the bottom, with collapse and gravitational structures throughout. Location: El Ben Mine near Lincoln, Illinois.

V-shaped system, particularly if roof bolts are anchored below the major slips.

Clay dikes in the Herrin (No. 6) Coal seem to differ from those in Springfield (No. 5) Coal. Those in the Herrin (No. 6) Coal have been studied in various mines, including detailed studies and mapping of clay dikes at mine A in west-central Illinois. Size, shape, orientation, and lateral and vertical extent of clay dikes in the Herrin (No. 6) Coal in mine A are highly variable, but the many features they have in common are used to distinguish them from clay dikes in other coals. Some impressions of their variability can be gained from photos and sketches that portray the full spectrum of clay dikes (figs. 105-115).

Most of the clay dikes at mine A are inclined, generally at less than 70° , in contrast to those in the Springfield (No. 5) Coal, which are nearly vertical. The filling is confined mainly to the coal itself, often only to the upper portion of the seam. In some places clay penetrates the lower foot of the roof sequence. Shear planes are found within nearly all clay dikes (figs. 113-115), cutting the coal and penetrating the immediate roof. Large clay dikes may attain a width of several feet and penetrate the entire coal seam.

Smaller clay dikes generally affect only

the upper part of the coal, and the associated shear planes steepen downward and end in a set of "goat beards" (figs. 108 and 109). The smallest clay dikes affect only about the top foot of the coal seam. This, in addition to other evidence, indicates that the material in the clay dikes was derived from roof lithologies.

Clay dikes are associated with clay-dike faults. In many places, especially in mine A, clay dikes are clay-filled clay-dike faults, around which the bedding of the coal shows specific, yet peculiar, disturbances. Displacement of up to several feet near the top of the coal has normally diminished to very little or no displacement at the base of the Brereton Limestone, and any fractures in the limestone have "healed" sufficiently to prevent roof failure. False drag (reverse drag) is well exposed along the shear planes. Although the faults are normal, the bedding is upturned on the hanging wall and downturned on the foot-wall (figs. 92 and 108). In other words, the bedding tends to turn perpendicular to the fault plane. Local convergence of beds is another typical feature (figs. 94, 108, and 109) that is particularly noticeable toward sideward protrusions of

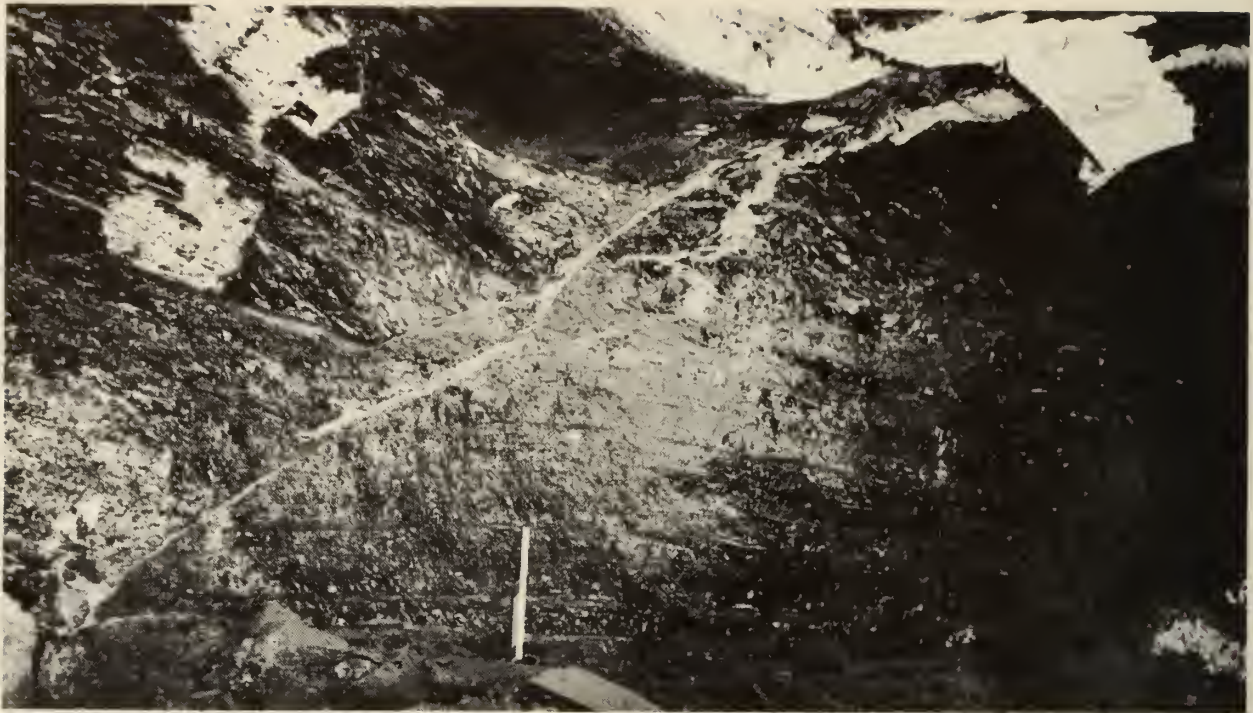


Figure 107. Clay-dike filling along clay-dike fault. Low-angle normal fault displays one foot of throw at the top of the Herrin (No. 6) Coal. Note the normal drag in the coal at the lower footwall and the false drag in the coal at the hanging wall. Location: mine A, west-central Illinois.

clay dikes (clay sills), but is also apparent at the tip of small shear planes, which branch off from the main fault in the coal and decrease in inclination (figs. 109 and 113).

The filling of clay dikes in mine A is generally a soft, light-colored clay similar in appearance to underclay; however, where a clay dike reaches the coal floor, the differences between the underclay and dike filling are usually distinct. In most cases the underclay is slightly darker. Where clay dikes or clay-dike faults penetrate the coal seam all the way to or into the underclay, the underclay commonly has buckled up and protruded upward as a hump into the coal. A sharp contact can always be found between the clay dike material and the underclay, however. The dike filling seems to be material that was derived from shales or "clod" of the immediate roof. In some places, fragments from the adjacent shale, coal, and limestone form a breccia in the fine-grained clay matrix, particularly near the contact of the coal and roof (figs. 113 and 114).

In mine A, clay dikes are most prominently developed where the Brereton Limestone forms the immediate roof, but they occur under all roof types. When clay dikes form under the Anna Shale or the "Jamestown Coal interval" forming the immediate roof, they tend to be thinner and contain clay with more greenish cast than dikes under limestone roof.

Many individual clay dikes may be traced along curving paths for hundreds of feet. Commonly they branch and reunite. The appearance of a dike, however, may change considerably along its strike. The dikes strike parallel to the trend of the boundaries and dip toward the interior of the lenticular roof rock bodies.

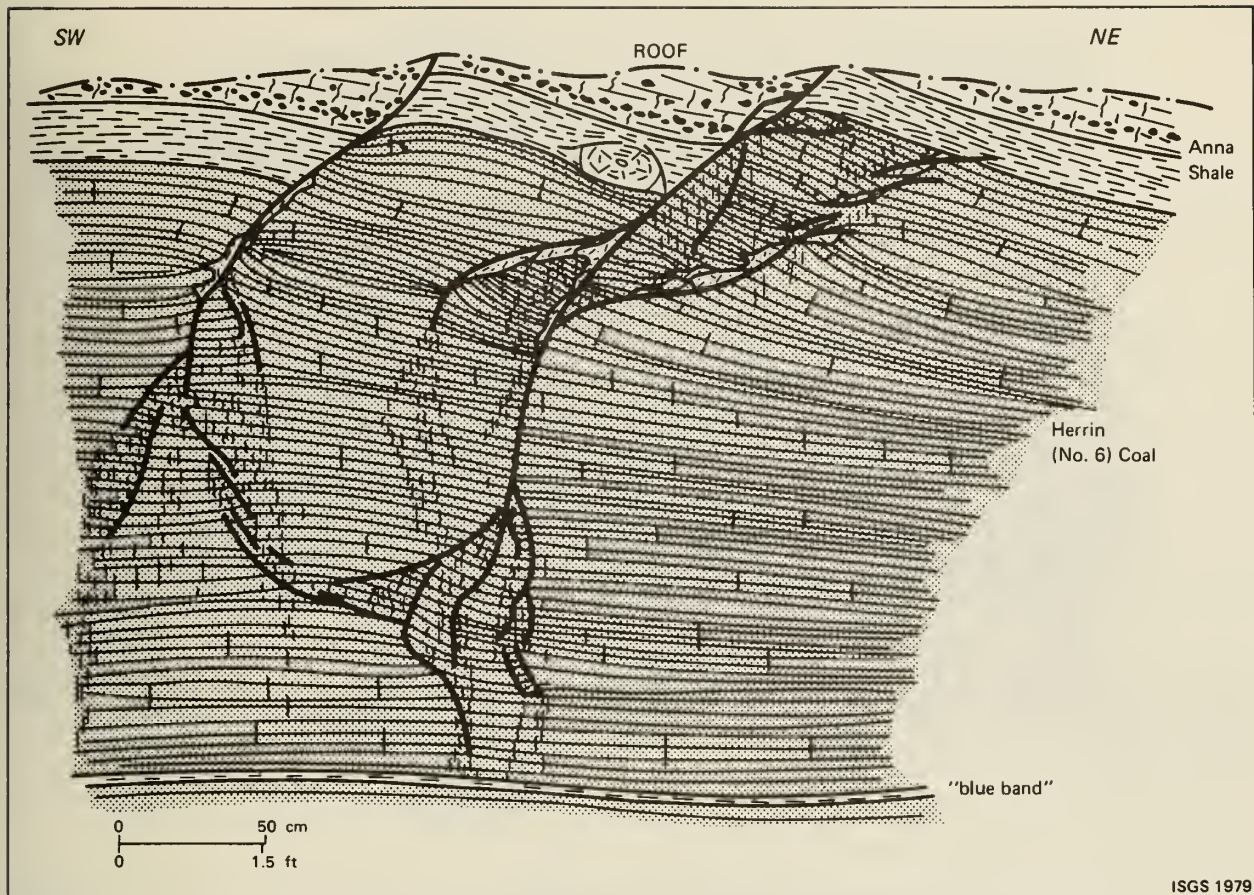


Figure 108. Clay-dike faults with clastic dikes in the Herrin (No. 6) Coal and Anna Shale. Displacement at top of coal is more than one foot; however, the "blue band" has not been cut. Horizontal extension in the coal above the "blue band" results from dip-slip shearing along the low-angle faults and from rupturing and opening of numerous en echelon extension fractures ("goat beards"), which are filled with abundant pyrite and in some places with barite and calcite. Note false drag and tilting of blocks between the faults, and convergence of coal beds at some ends of clastic dikes and sills. Location: mine A, west-central Illinois.

Clay dikes are rare in the mines that have gray shale roof in the "Quality Circle" area. A few very thin and small clay dikes in the upper part of the coal seam at mine B have been found (fig. 44). The rarity of clay dikes in southern and southwestern Illinois underneath thick gray shale roof rock may possibly be related not only to the difference in roof rock type but also to the decrease in frequency of clay dikes southward within the Illinois Basin (cf. Damberger, 1970 and 1973).

At mine A even the largest clay dikes have little influence on roof and rib stability. One reason is that most clay dikes occur under limestone roof. Another is that the dikes usually do not extend far up into the roof. The highest clay dike observed in mine A is about 8 to 10 feet above the Herrin (No. 6) Coal in the Lawson Shale. The clay dike that extends the longest distance through a rock-stratigraphic interval was observed in a strip mine in Peoria County. This clay dike truncates the Danville (No. 7) Coal and penetrates down through the Herrin (No. 6) Coal.

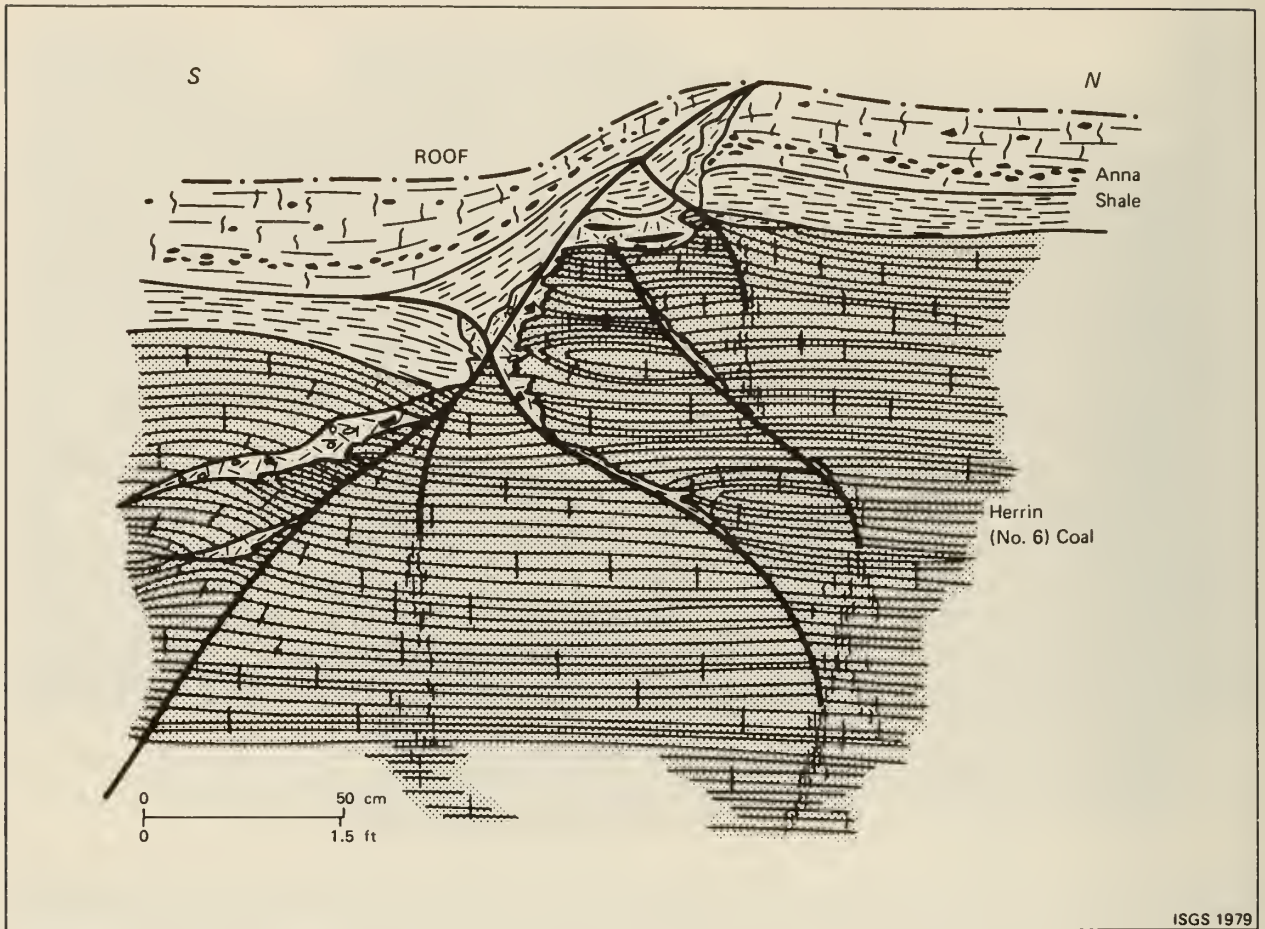


Figure 109. Clay-dike faults with clay dikes in Herrin (No. 6) Coal and Anna Shale. Structural features associated with clastic dikes in coal and clay-dike faults in coal are (1) low-angle normal faults that steepen downward as they penetrate the coal seam and dissipate into "goat beards," (2) en echelon extension fractures ("goat beards"), (3) false drag, although dip-slip normal movement occurred, (4) features of soft-sediment deformation, particularly thinning and thickening of Anna Shale benches, (5) clastic dikes, which locally lead into clastic sill features, (6) convergence of coal beds, mainly at tips of clastic sills, and (7) dike filling that consists of a fine-grained matrix with brecciated, angular coal and roof rock fragments. Brittle and soft-sediment deformation occur within the same deformational action. Location: mine A, west-central Illinois.



Figure 110. Complex clay dike in the Herrin (No. 6) Coal. Roof is Brereton Limestone which is displaced downward to the east. Fusain layer in the center of the coal seam is bent downward east of clay dike, fractured within the clay dike, and offset immediately west of the dike. Note the associated small low-angle clay dike faults and the numerous extension fractures and "goat beards," and the coal fragments in the clay matrix. Location: study area 1, mine A, west-central Illinois.

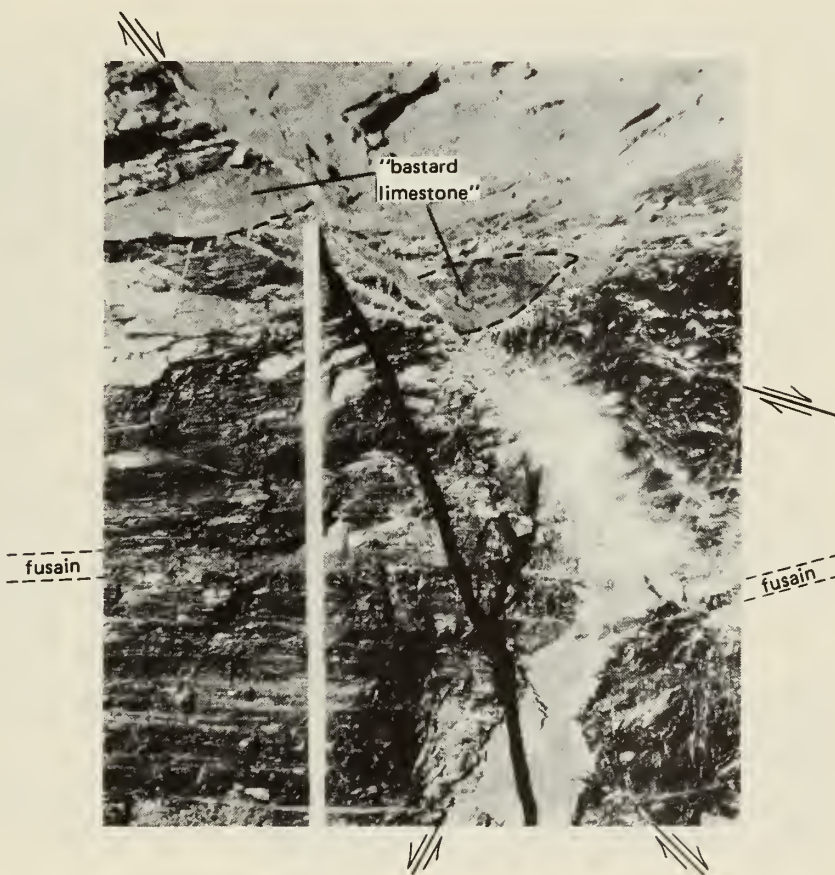


Figure 111. Detail of figure 110.

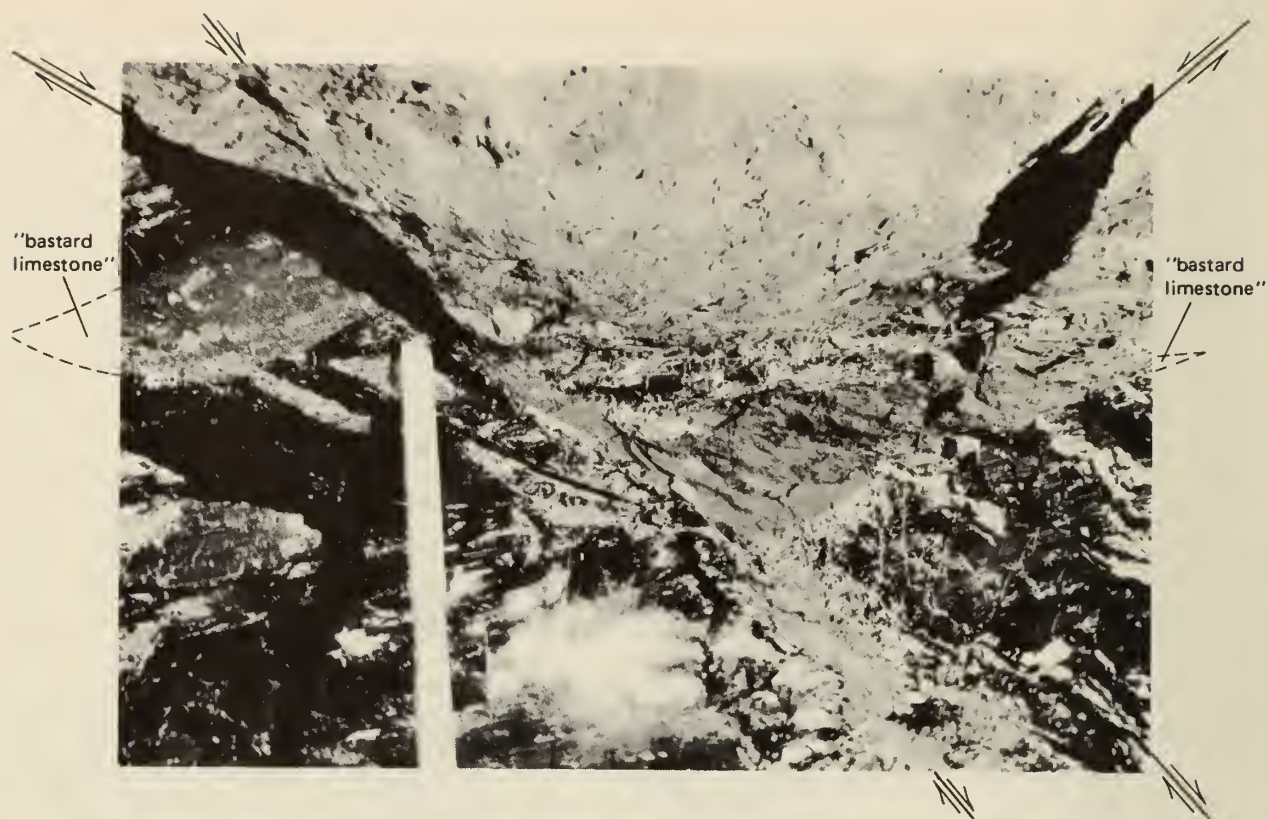


Figure 112. Detail of figure 111.

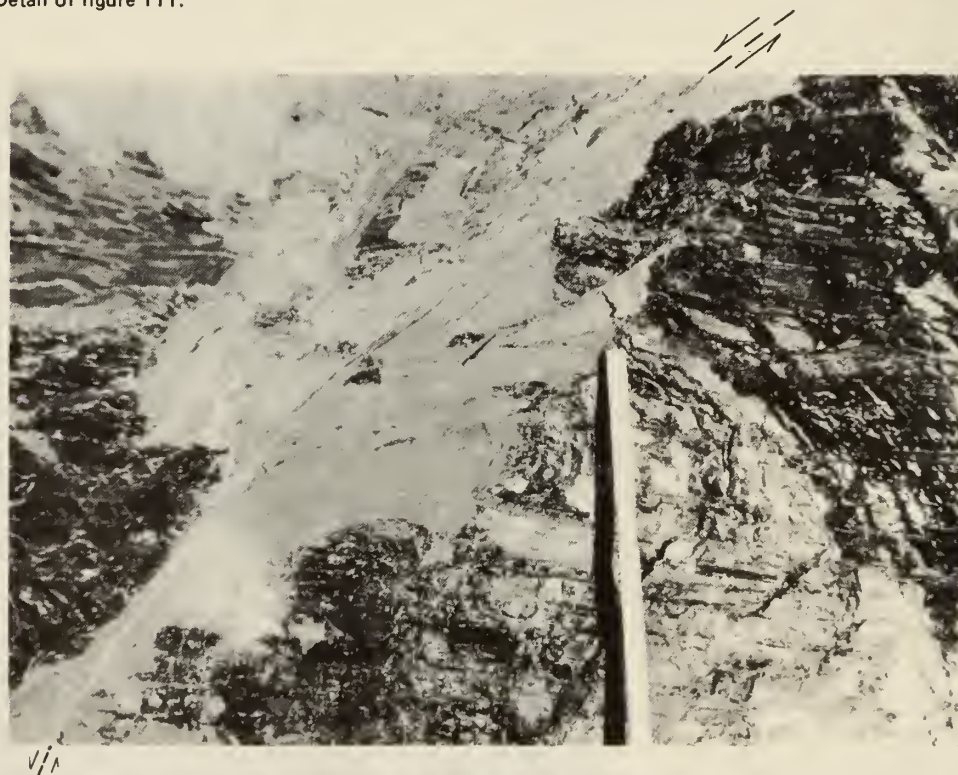


Figure 113. Clay dike and clay-dike fault in Herrin (No. 6) Coal. Angular fragments of unaltered and altered black shale from the roof and of coal in the clay matrix demonstrate the brittleness of the material during deformation. Synthetic and antithetic minor faults are displayed. Note also the plastic behavior of the coal, particularly at the end of the small clay intrusion upward, in the upper footwall block. Displayed there is a convergence structure of the coal laminae. Location: mine A, west-central Illinois.



Figure 114. Detail of figure 113.



Figure 115. Very low angle clay dike along clay-dike fault which truncates and displaces Herrin (No. 6) Coal and Anna Shale. Anna Shale is intensely altered and is cut by numerous small irregular clay dikes and clay sills. Note angular interface of the coal and the clay dike and coal fragments in clay dike. Location: mine A, west-central Illinois.

MAPS AND EXPLANATIONS OF THE GEOLOGY IN SELECTED STUDY AREAS

Three groups of study areas for in-mine mapping were selected. Each group represented a principal type of roof strata commonly found above the Herrin (No. 6) Coal. Several study areas for each group were mapped in detail using conventional field techniques. Regional trends and variations of the roof strata were studied using computer-generated maps of thickness and structural contours.

Results of in-mine mapping of selected study areas

The maps demonstrate the close interrelationship between the lithologic boundaries; the effects of the shapes of the rock bodies; the distribution, frequency or spacing, and trend of structural features; and the stability of the roof rock after mining. These relationships vary according to the differences in the lithologic sequence of the roof rocks, as described earlier.

Common characteristics of specific roof types—for example, black shale-limestone roof or gray shale roof—can be mapped and then easily determined and described. It is necessary to map as many recognizable details as possible. To avoid overcrowding with station numbers, the lithologic data maps were drawn separately from maps of structural features and maps of deformation caused by mining. From these maps compilation and combination maps were obtained.

STUDY AREAS IN BLACK SHALE-LIMESTONE ROOF

Figure 116 shows the positions of study areas 1, 2, and 3, which were selected within accessible mine workings adjacent to structural anomalies. None of these study areas is at an extremely high or extremely low elevation of the base of the coal. Study area 2 was chosen in the vicinity of and within an active mining area, whereas study area 1 is an area that had been mined years ago. Details of the three areas are given in figures 117 through 138. The station maps (figs. 117, 124, and 132) from study areas 1, 2, and 3 show the density of stations and data points for the field descriptions and may be used to evaluate or assess the validity of interpolation and interpretation.

The maps of lithologic data (figs. 118, 125, and 133) are presented for the same reason but especially to demonstrate the accuracy of the lithologic maps (figs. 119, 126, and 134). Detailed data of the lithologic roof sequence were obtained mostly from areas of unstable roof, where roof falls had exposed the overlying strata. Entirely stable roof provides data only on the immediate roof. The lithologic maps (figs. 119, 126, and 134) show a local patchy occurrence of the Anna Shale and its wedging toward edges of more or less wide irregular lenses. The Brereton Limestone in study areas 1 to 3 appears in rather narrow, curvilinear, sinuous pathways above the coal. It overlaps the wedges of older Anna Shale lenses and also forms thin narrow wedges on both sides of the troughs. Although the thickness of the Brereton varies, an isopach map could not be produced because the stable roof conditions prevented data collection. With two negligible exceptions, roof falls occur only in areas where the Anna Shale or the "Jamestown Coal interval" form the immediate roof and the Brereton Limestone is less than two feet (60 m) thick or is absent.

A very close correlation between lithology and roof stability can therefore be inferred; however, it cannot be stated with certainty that Anna Shale

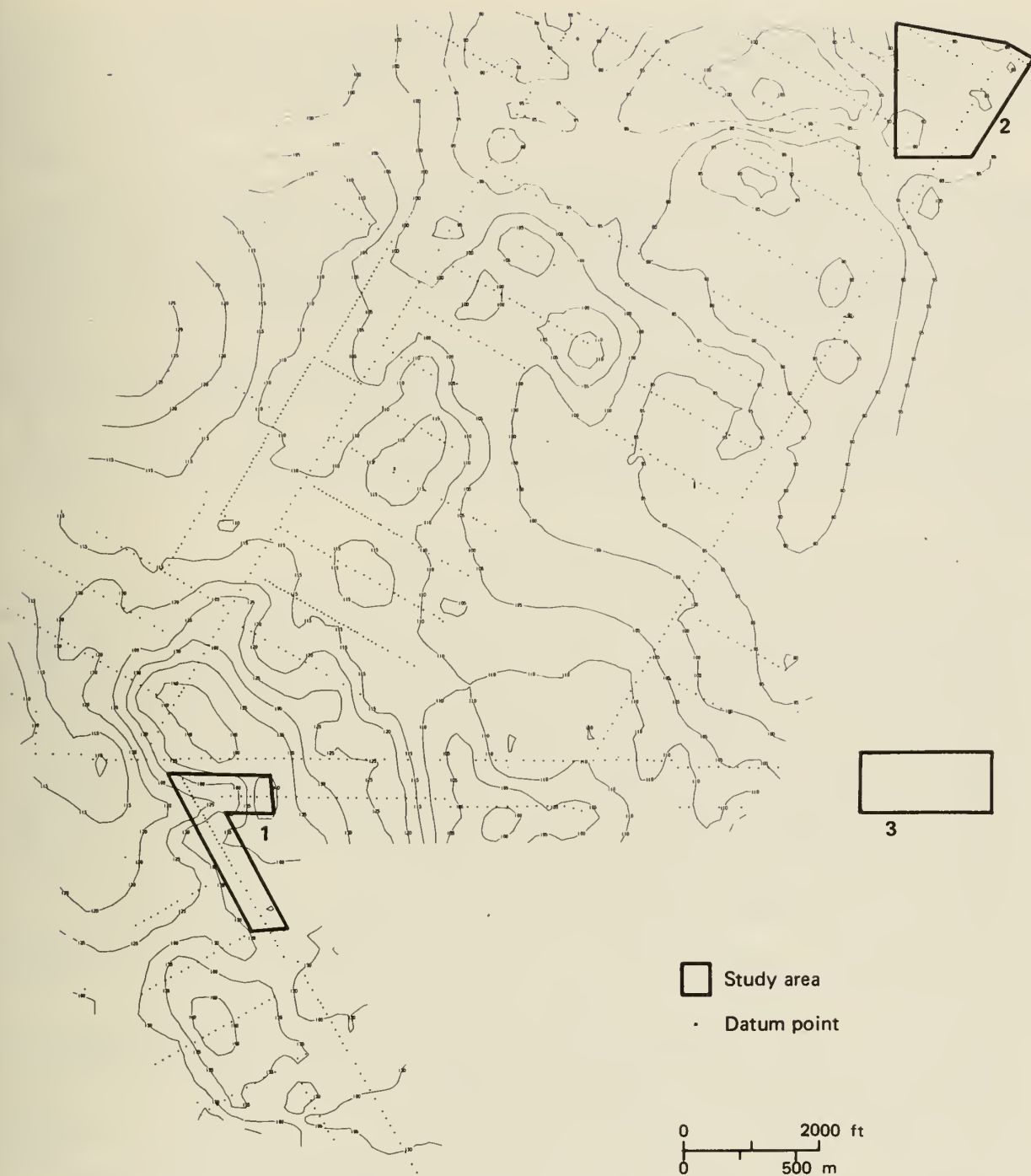


Figure 116. Map of the base of the Herrin (No. 6) Coal at mine A, study areas 1 to 3. The contour interval is five feet, and the grid size for computer generation is 200 feet.

roof is especially hazardous. Areas with two feet and more of Anna Shale without Brereton Limestone have been found in many places to be without roof problems. Where thick Anna Shale was truncated by faults and clay dikes (see figs. 127 and 129, areas G/4, G/7, E/3, or E/4), however, the roof was prone to fail.

In a few places both the Anna Shale and the Brereton Limestone are absent, and the "Jamestown Coal interval" directly overlies the coal. Since those places as well as those with a few centimeters of Anna Shale overlain by the "Jamestown Coal interval" are commonly also deformed by faults or shear fractures, it is difficult to determine whether the fractures and faults or the different lithologic conditions alone impose roof instability (see fig. 122, area A, B/3 and fig. 129, area G/4 or E/6).

The maps of the structural features in the roof (figs. 121, 128, and 136) are most important to prove the close correlation between the distribution and shape of lithologic bodies and the orientation, spacing, and distribution of deformational features such as faults and clay dikes. Many details concerning such relations have been described earlier and can easily be deciphered from the maps.

Three types of normal faults have been mapped:

1. Major clay dike faults displacing the entire coal seam with vertical throws as much as 18 feet (5.4 m). Their strike and dip is independent from the orientation and from the shape of local lithologic bodies (e.g., fig. 122, A/9, B/8, C/7, C/9, D/9, E/8, F/7, G/6, and G/5, or fig. 129, H/6 to 12 and E/2 or F/2 to 6). Usually these faults form an en echelon pattern.
2. Clay-dike faults and clay dikes displacing the top of the coal seam more than one foot and also truncating the bottom of the seam into the under-clay. These faults also tend to be free of significant influence by local lithologic bodies and their boundaries, which they bisect (e.g., fig. 129, areas H/3, G/3, 4, F/5, E/6, D/6, C/7, and B/8).
3. Minor clay-dike faults and clay dikes displacing the roof and the top of the coal, not cutting through the entire coal seam into the floor.

Characteristics and behavior of the minor clay-dike faults and clay dikes are especially well displayed in figure 129, the area E to H/5 to 11:

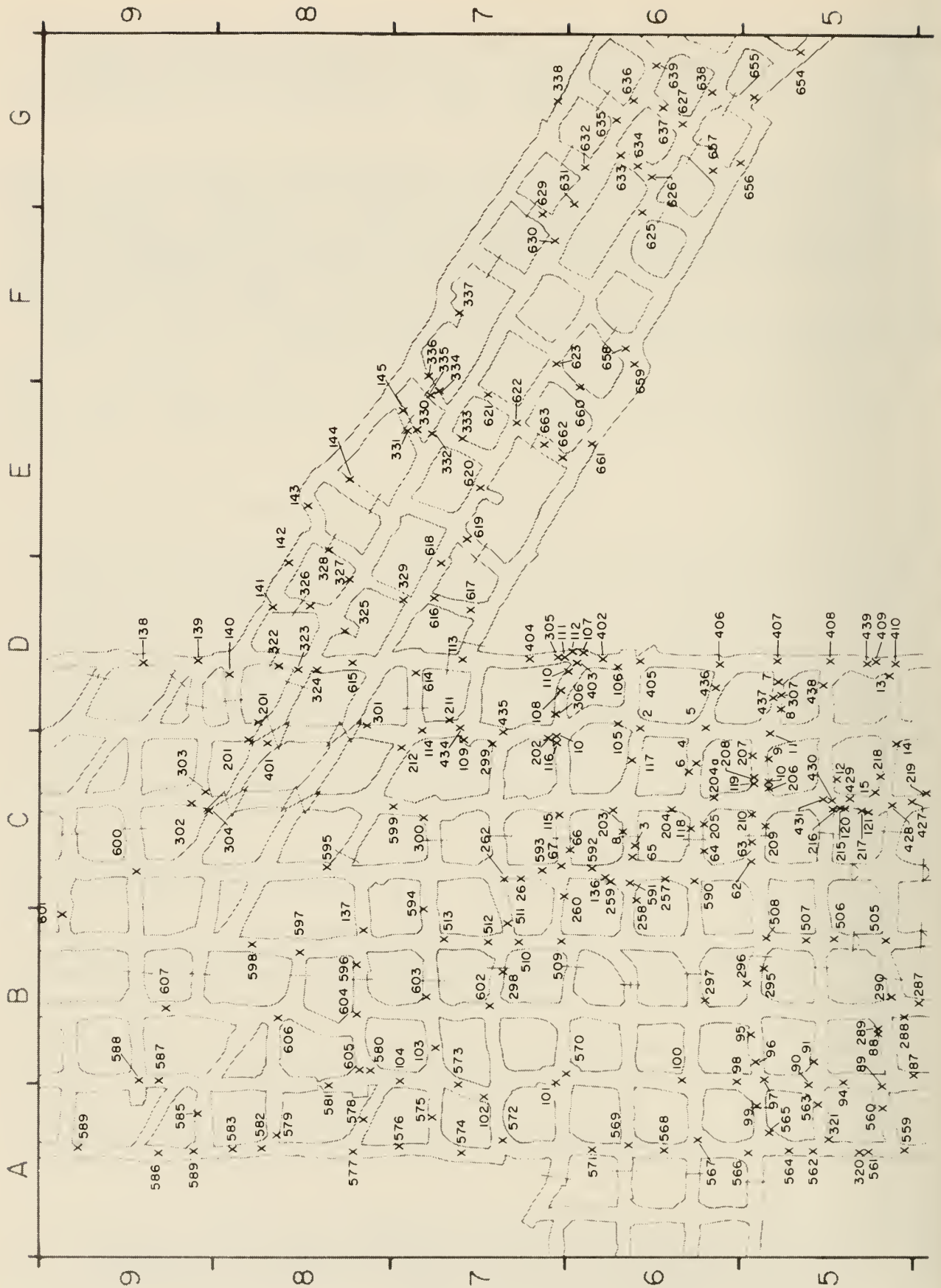
1. Most of the minor clay-dike faults, as mentioned above, are restricted to the lithologic body within which they occur, and they seldom cross the boundaries laterally into another lithology.
2. The dominant strike is more or less parallel to the lithologic boundaries in the roof.
3. The faults in Anna Shale roof dip toward the center of the Anna Shale lenses. Faults and clay dikes in Brereton Limestone roof dip toward the centers of the limestone bodies.
4. The clay dikes were dominantly formed under Brereton Limestone roof, and they are especially prominent where it forms the immediate roof and the Anna Shale is absent.

The maps of structural features, lithology, and roof falls (figs. 122, 129, and 137) show the close relationships between lithology and deformational features and especially the dependence of roof stability on the deformational features that occur in particular lithologies or lithologic bodies. Faults and clay dikes, which truncate a roof that has thin or no Brereton Limestone in the

succession, increase the hazard of unstable roof considerably (see, for instance, fig. 122, area C and D/1 to 3). Roof without Anna Shale but rather thick Brereton Limestone rarely fails, even if the limestone is intensively cut by narrowly spaced faults and clay dikes (compare fig. 122, northern part, and fig. 129).

Not all deformational features have an immediate and serious effect on roof stability, as indicated in figures 123, 130, and 138. Joints, for instance, seldom pose any serious problems for mine roof control. With the exception of large spheroidal concretions, other mapped data, which are seldom shown on the maps, have only secondary effects on roof stability. "Bastard limestone" occurrences do not impose a roof hazard themselves, but they indicate the vicinity of a lateral boundary between two lithologies above the coal, as shown in figure 130, areas E/2, E/3, E/4, G and H/6 and 7 and F/7 to 9).

Note: The scale of the following maps, figures 117 through 148 (unless otherwise indicated as on computer maps) is 200 feet (61 m) between grid points at the margins of the maps.



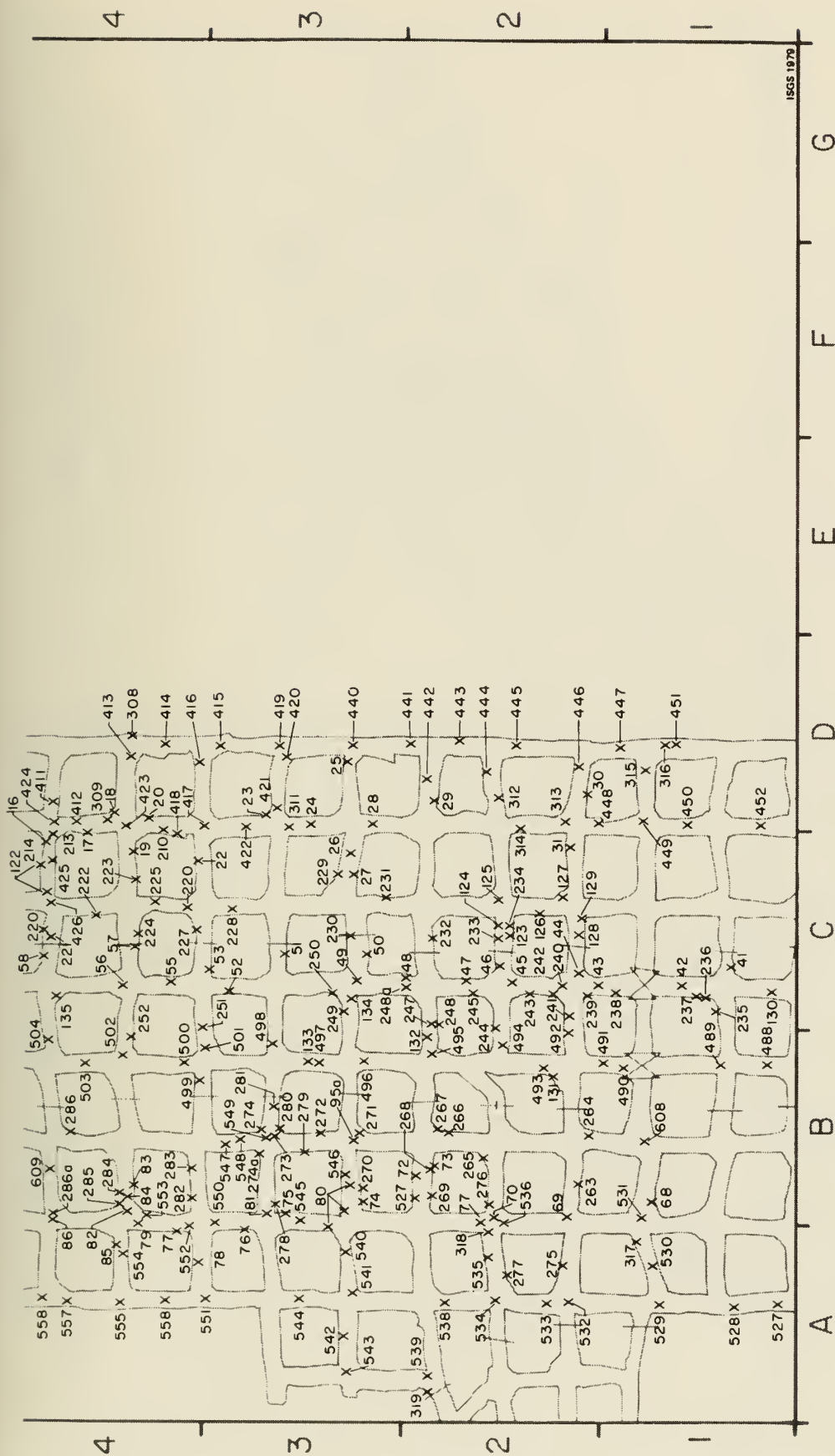


Figure 117. Stations in study area 1 of mine A, at which detailed studies were performed and notes were taken. The density of stations and data points allows evaluation of the confidence range for interpolation and interpretation. (Numbers on the map correspond to station numbers in ISGS mine notes.)

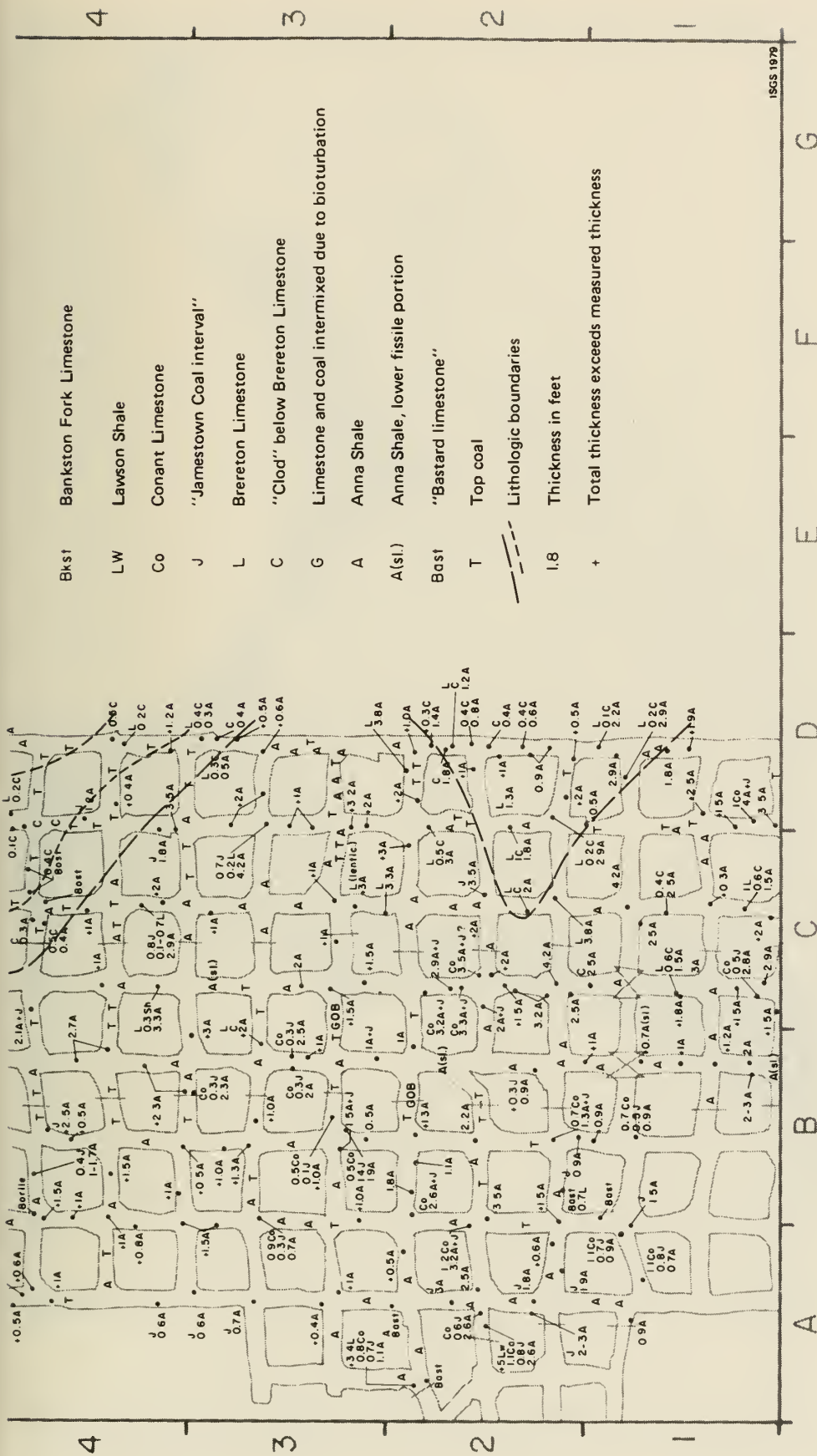


Figure 118. Lithologic data of the immediate roof strata of Herrin (No. 6) Coal in study area 1 of mine A. Areas of unstable roof yielded more data than areas of stable roof.



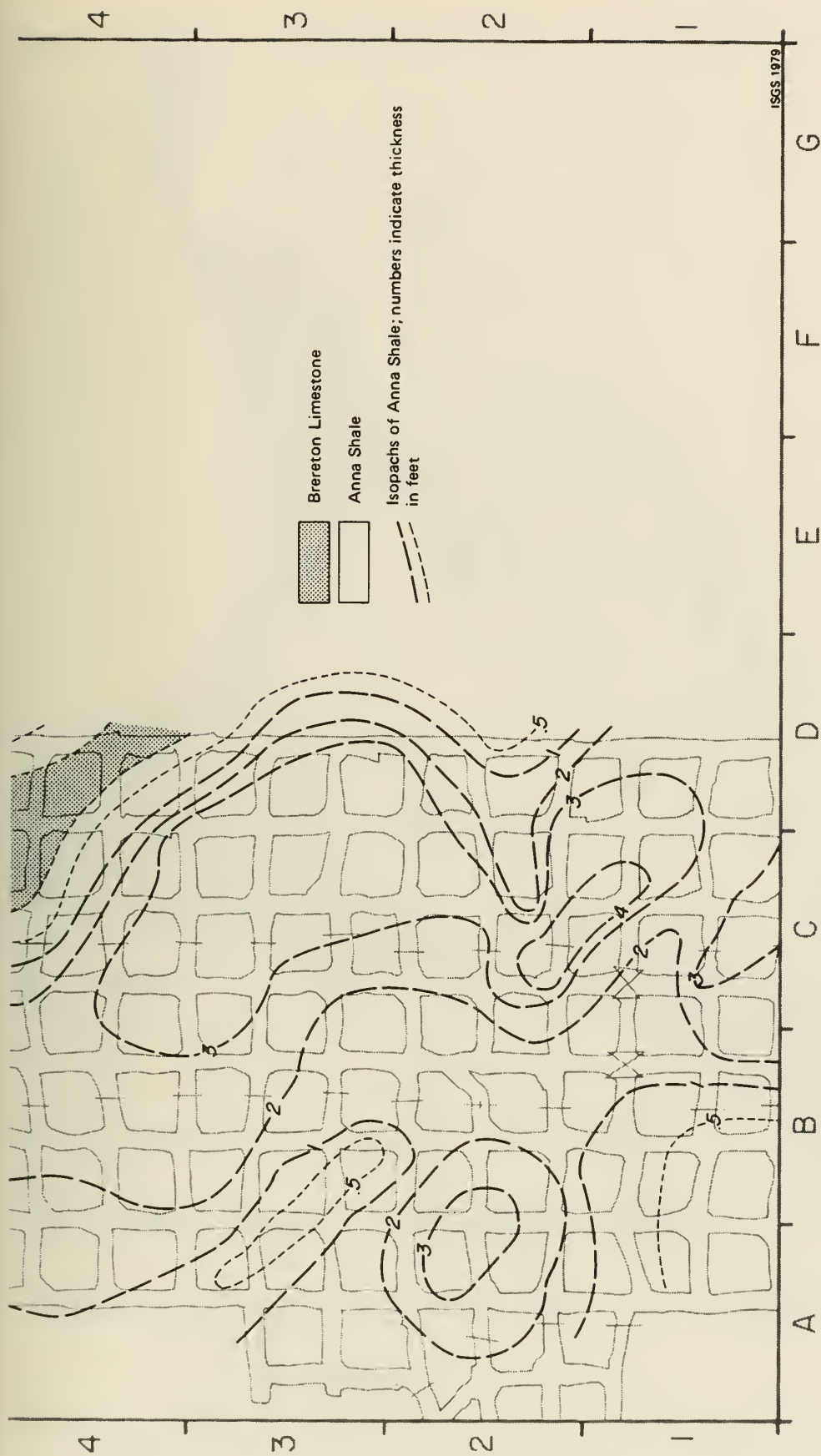
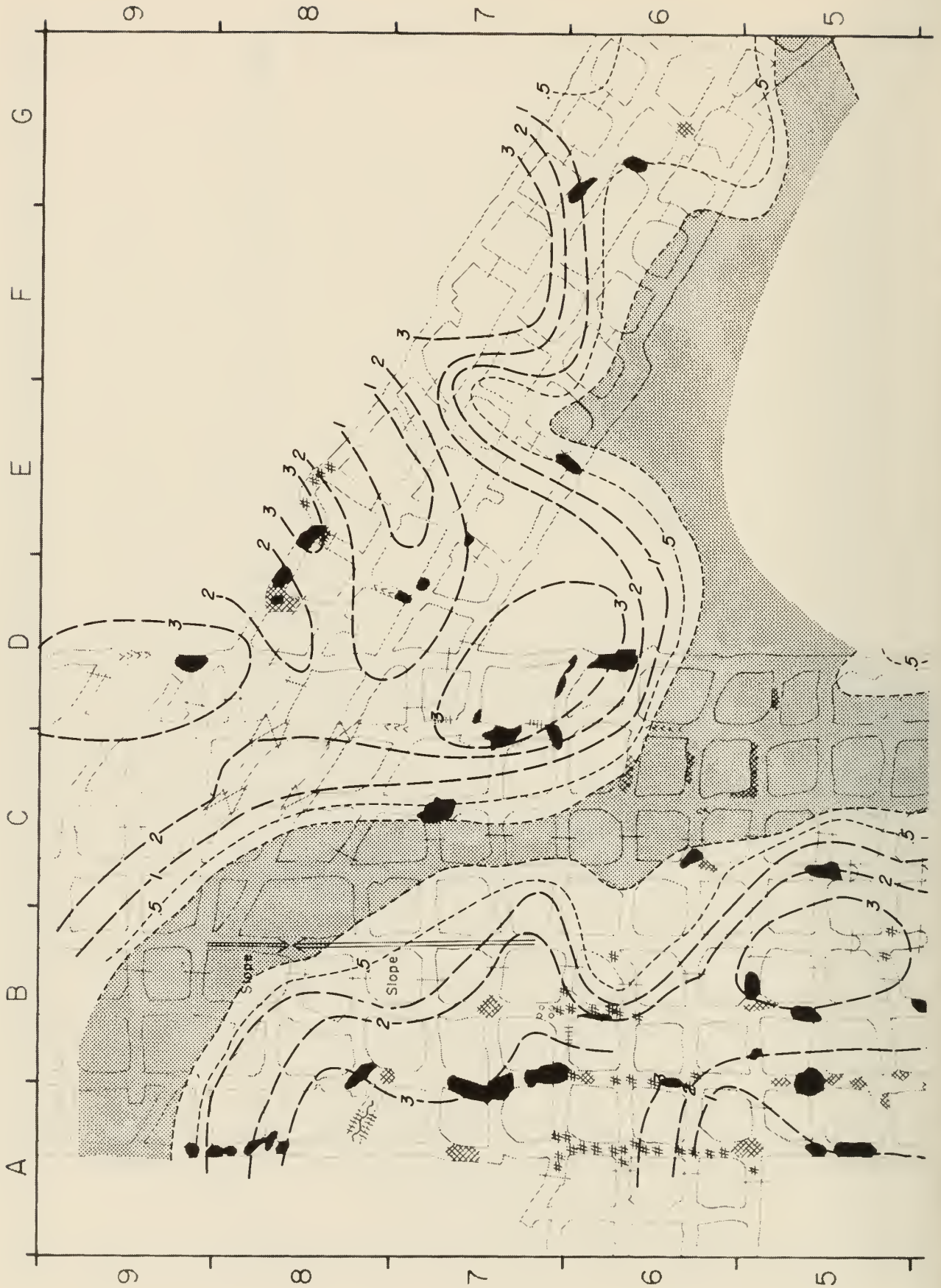


Figure 119. Lithology of the immediate roof strata of Herrin (No. 6) Coal and thickness of Anna Shale in study area 1 of mine A. Isopachs give the thickness of Anna Shale in feet; in stippled areas Anna Shale is absent and Brereton Limestone directly overlies the coal.



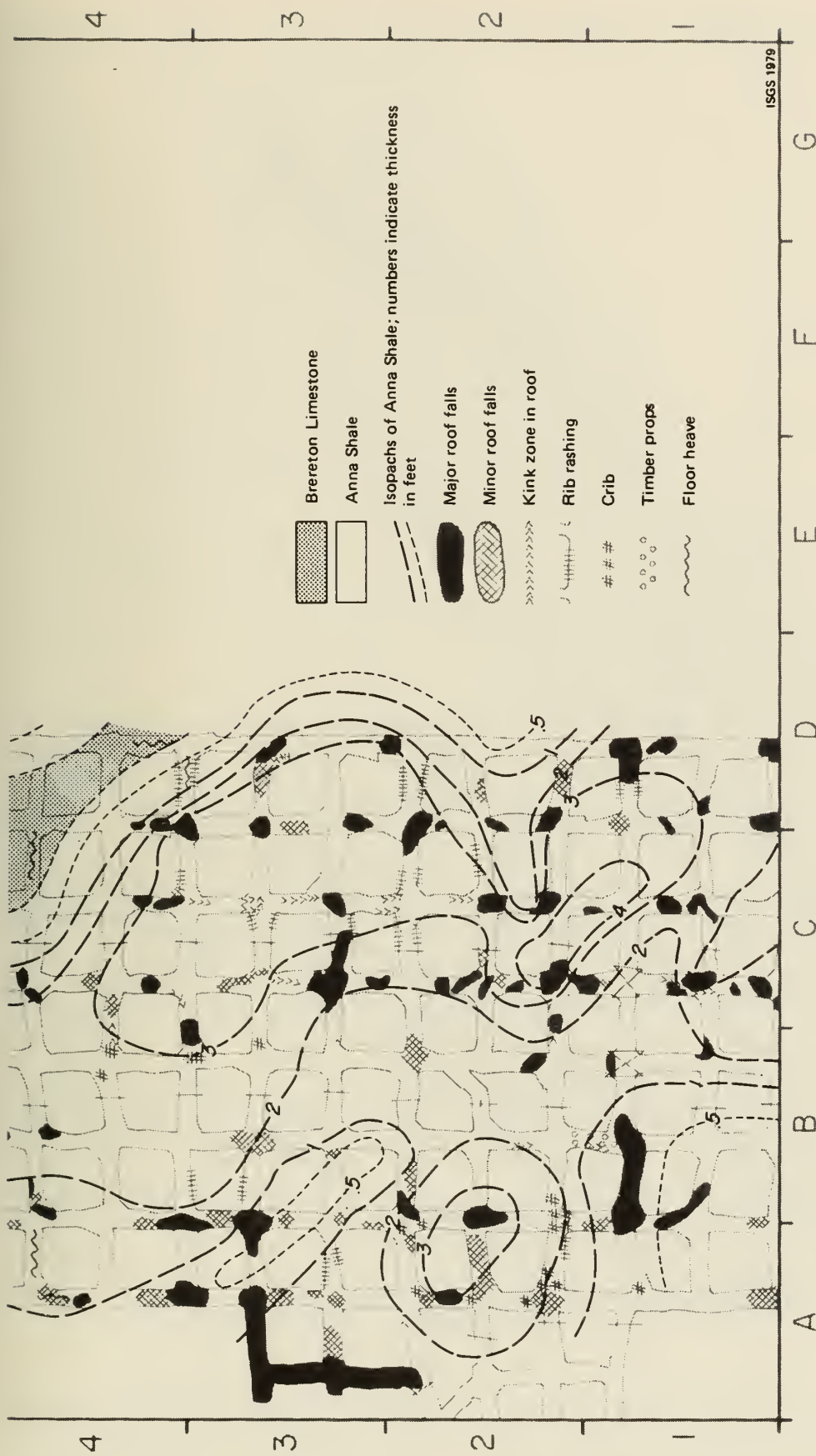
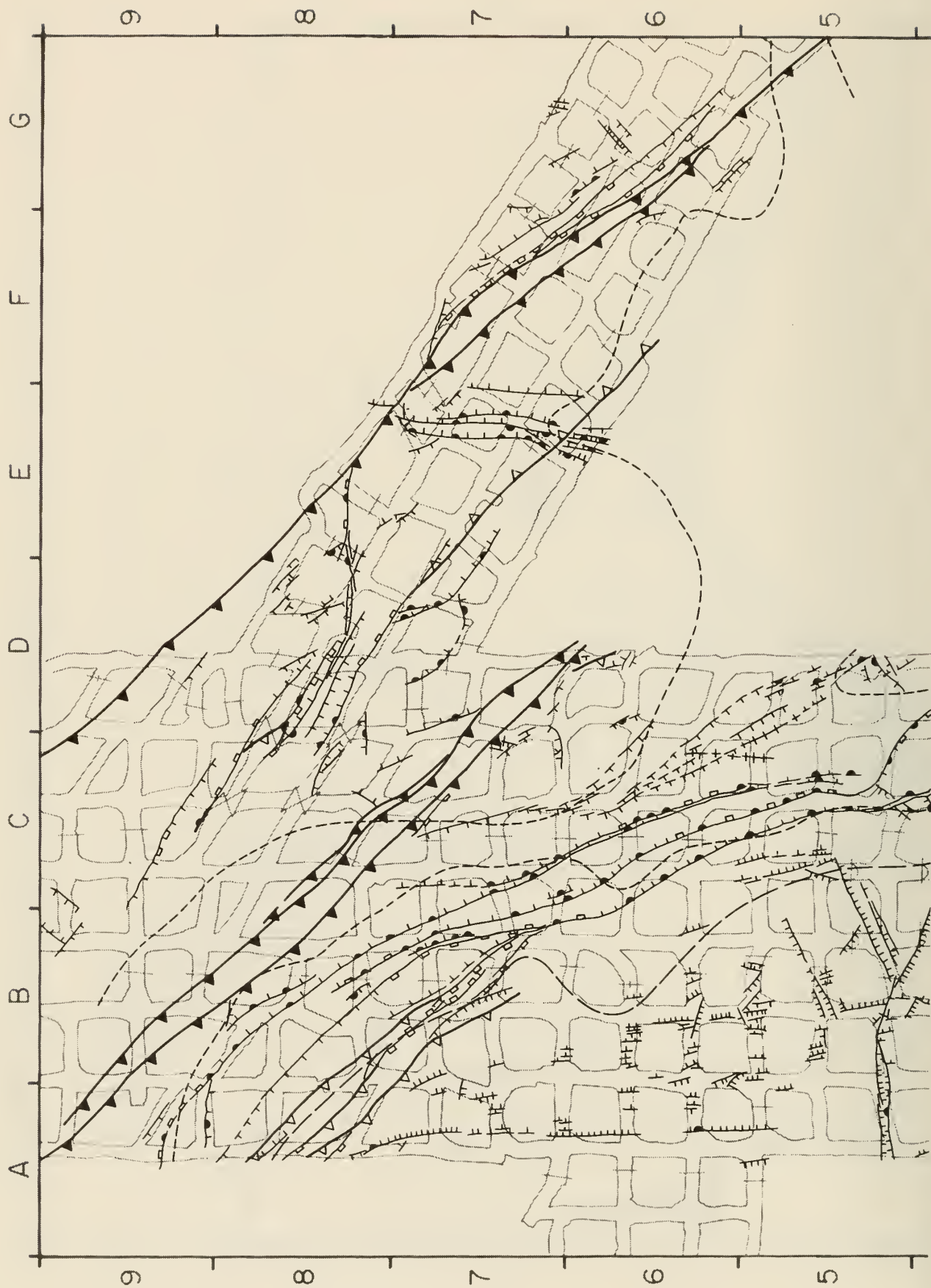


Figure 120. Distribution of roof falls and their relation to the immediate roof strata in study area 1 of mine A. No roof falls occur where Brereton Limestone directly overlies the Herrin (No. 6) Coal, although some shallow flaking of "clod" may occur locally.



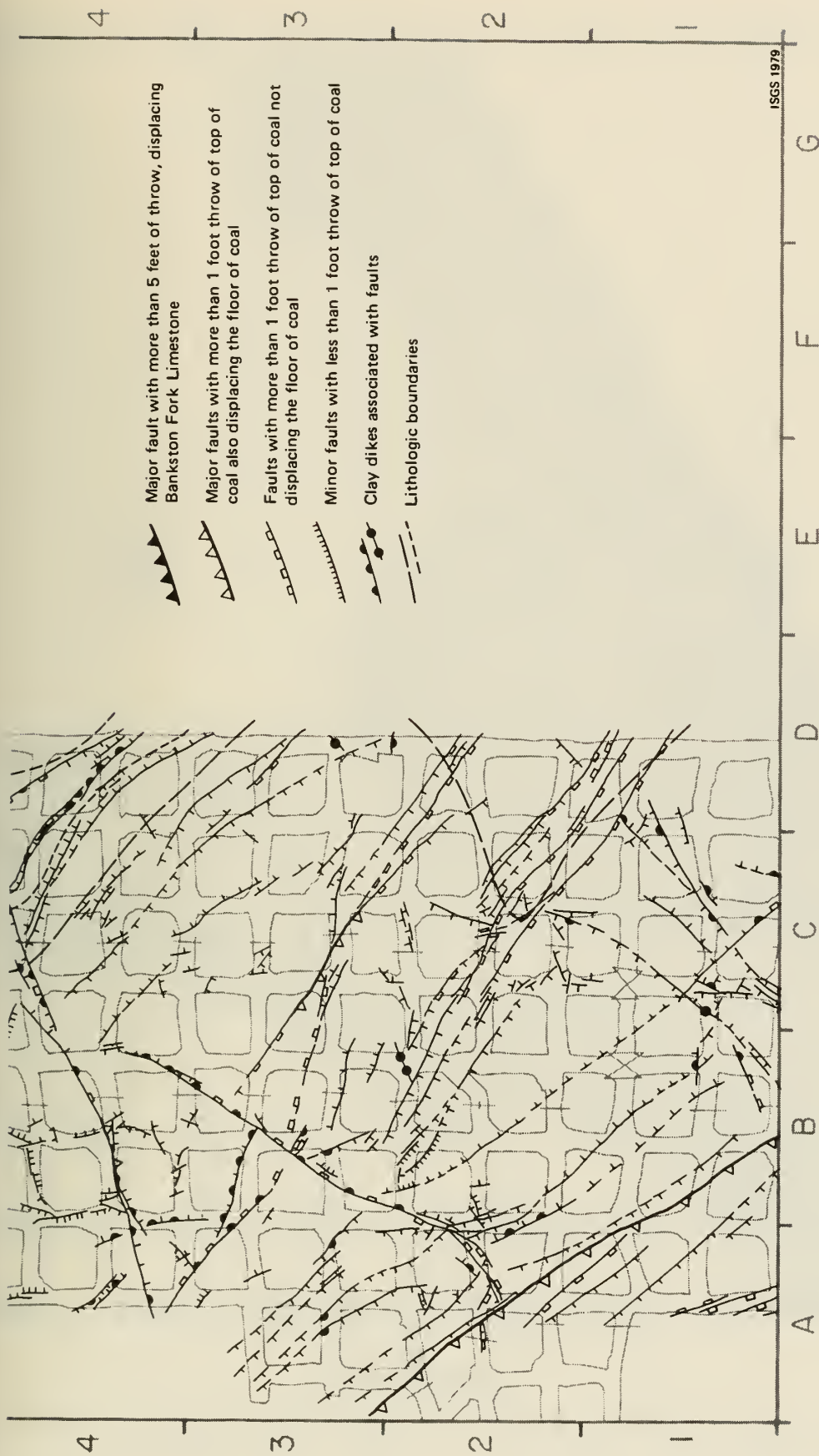
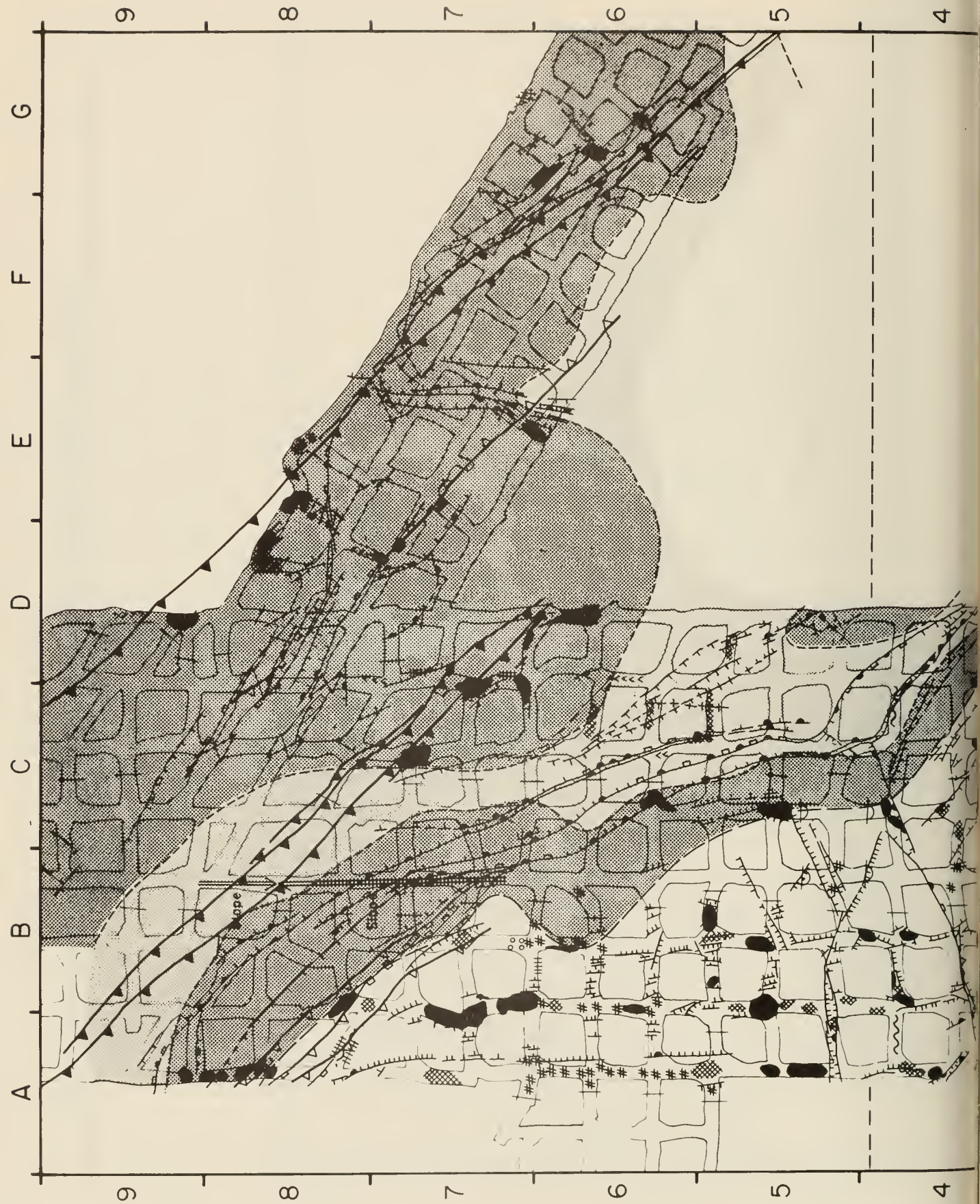


Figure 121. Clay-dike faults and clay dikes in Herrin (No. 6) Coal and its immediate roof strata in study area 1 of mine A. Position, orientation, distribution, and frequency of faults and clay dikes seem to have formed in close relationship to and are dependent upon the lithologic setting and facies distribution.



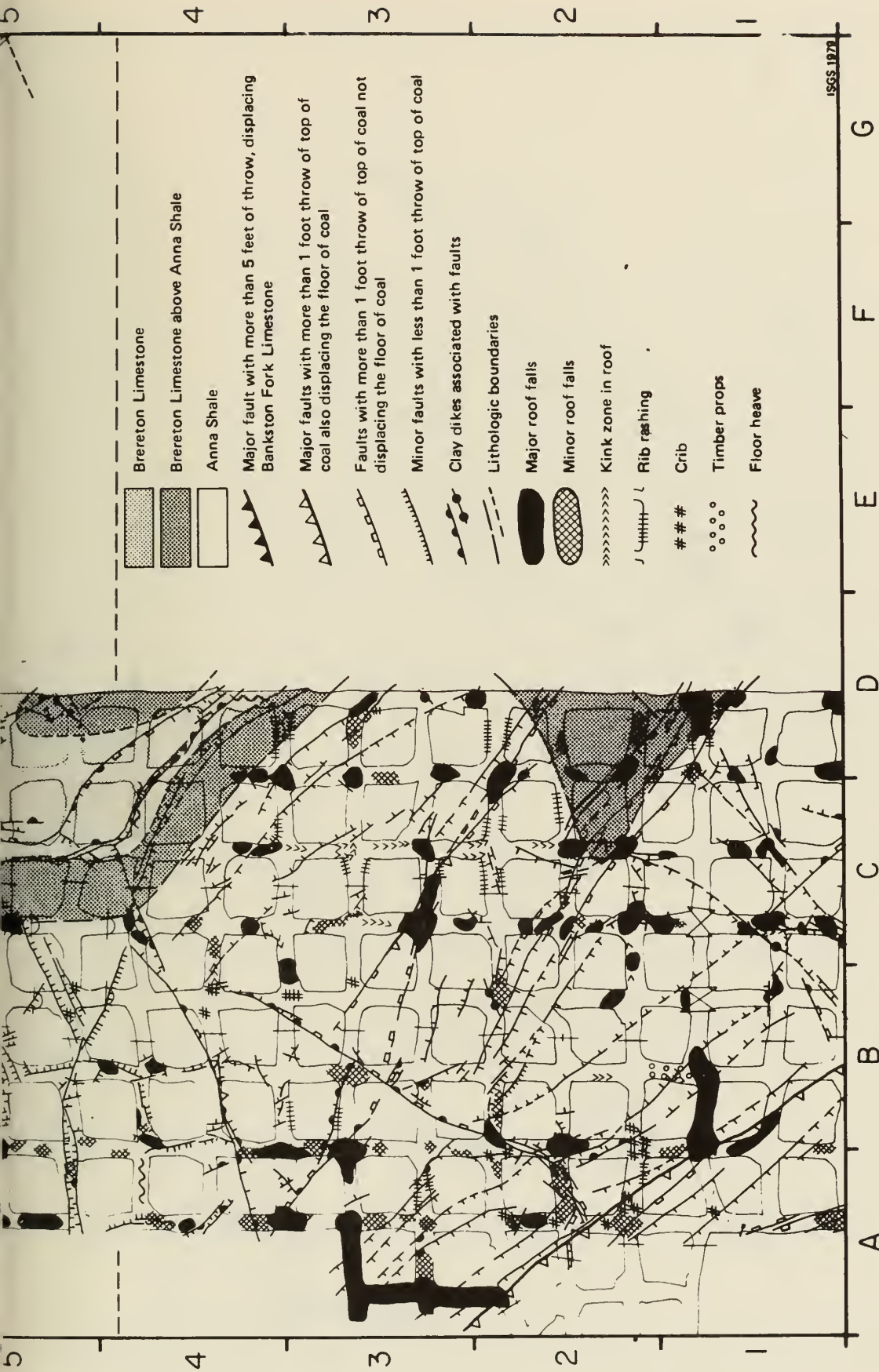


Figure 122. Distribution of lithology of clay-dike faults and clay dikes in the Herrin (No. 6) Coal and its immediate roof strata and of roof falls and other induced instabilities in study area 1, mine A. The occurrence of roof falls is a function of two geologic variables: (1) lithologic distribution and pattern of roof rocks and (2) structural setting and fault pattern. Roof falls are abundant along faults; however, there appears to be a greater affinity of roof falls to the lithology than to faults.



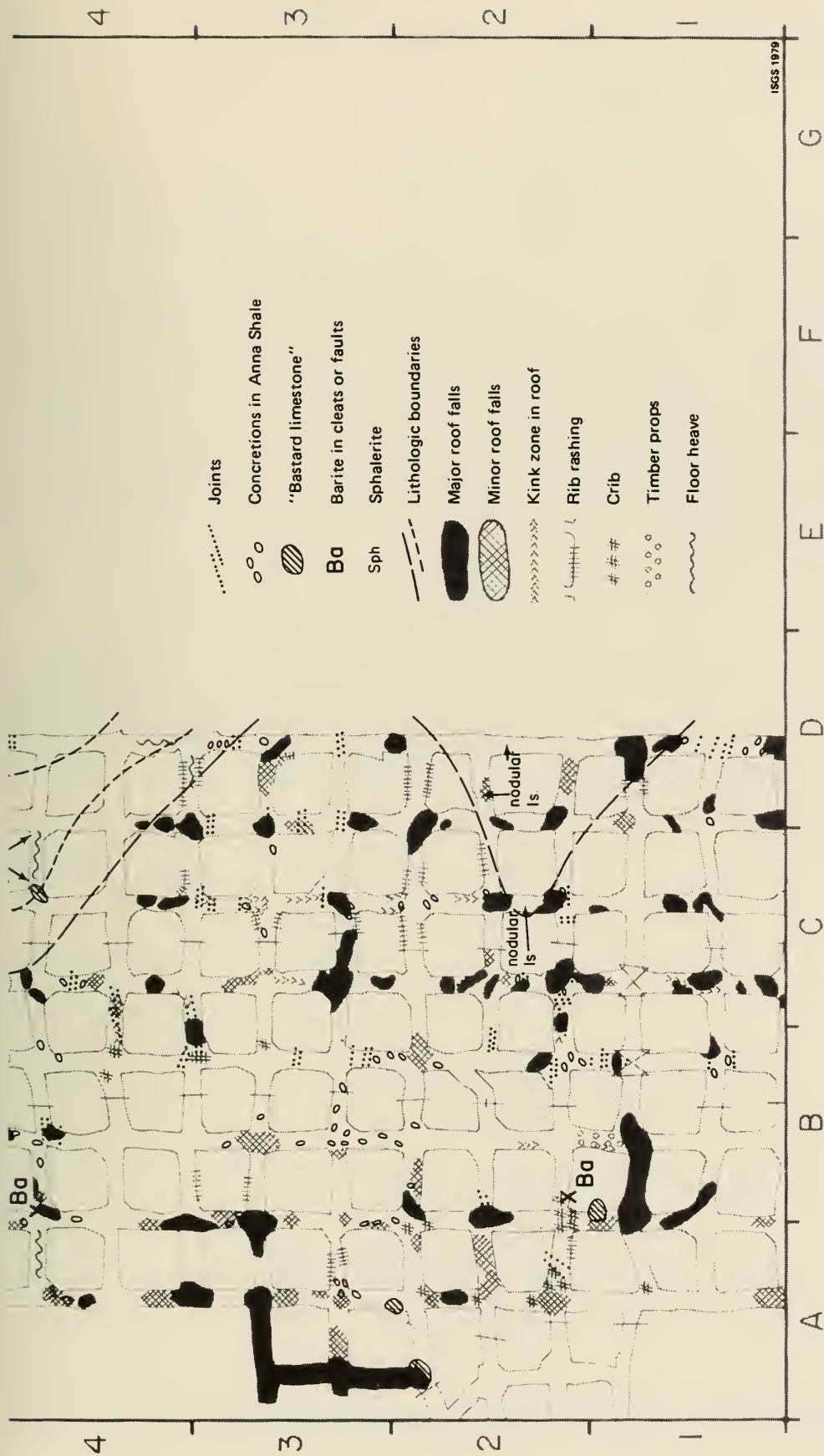
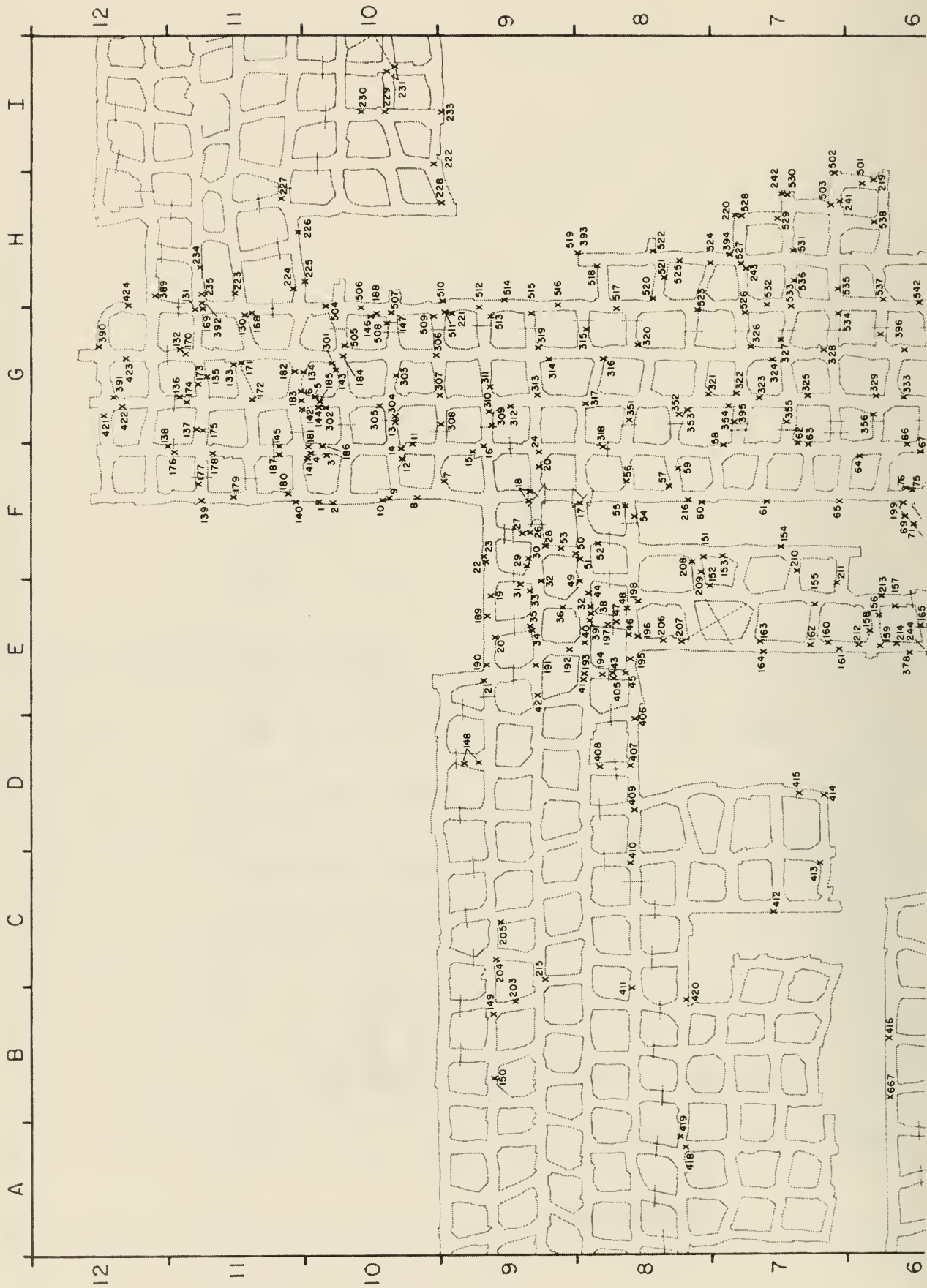


Figure 123. Distribution of additional data and lateral lithologic boundaries of the immediate roof strata of Herrin (No. 6) Coal in study area 1 of mine A.



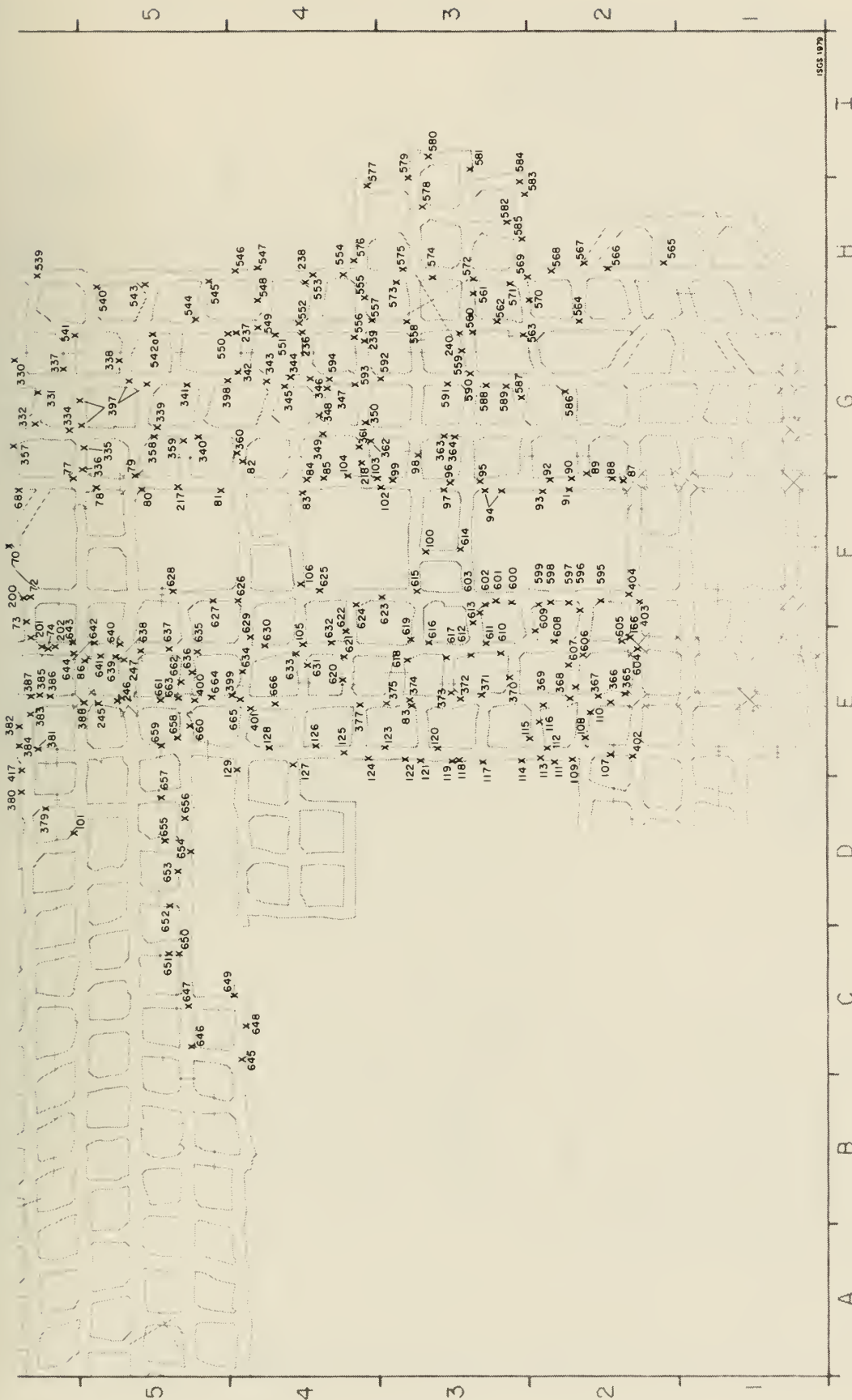


Figure 124. Stations in study area 2 of mine A, at which detailed studies were performed and notes were taken. The density of stations and data points allows evaluation of the confidence range for interpolation and interpretation. (Numbers on the map correspond to station numbers in ISGS mine notes.)



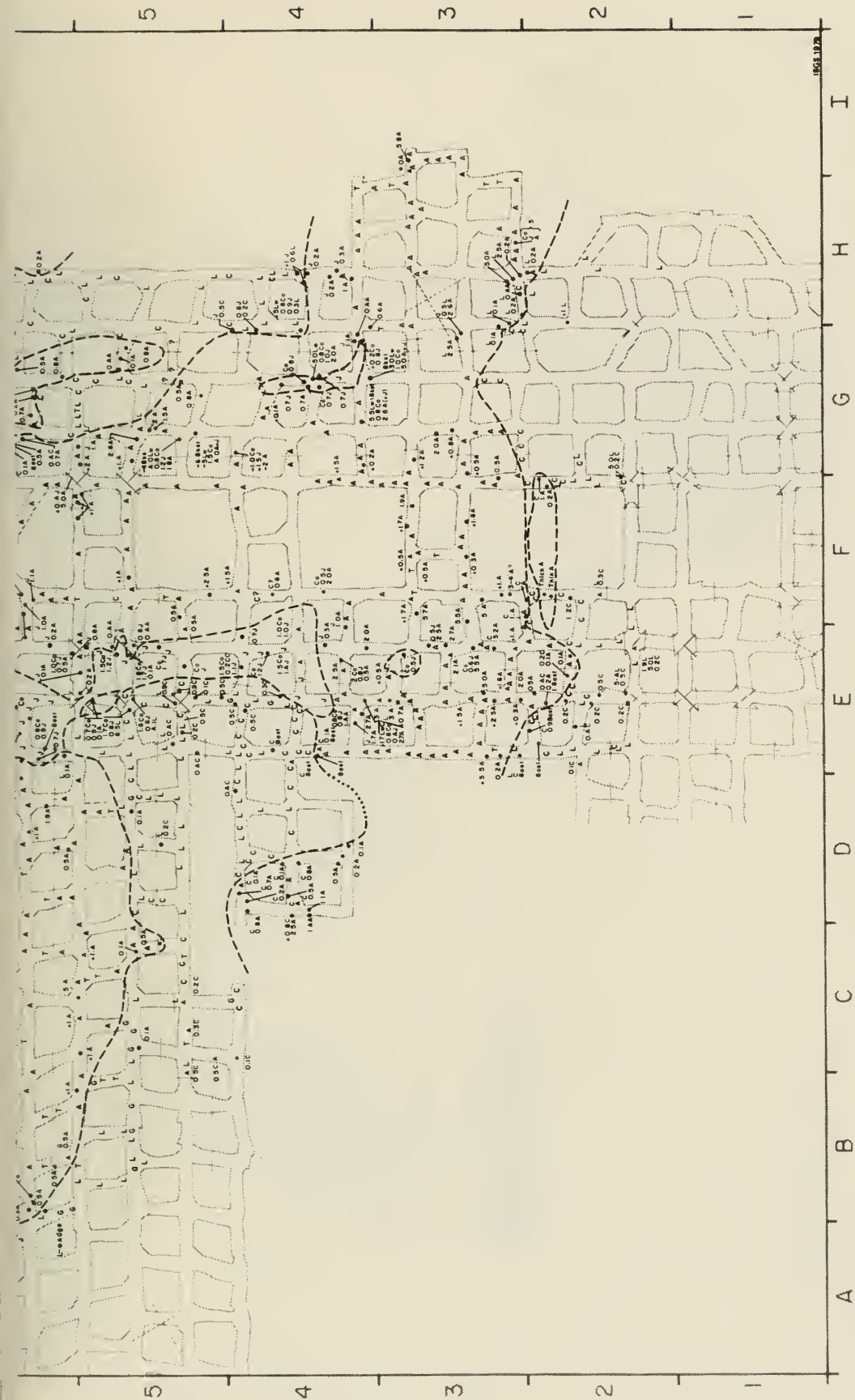
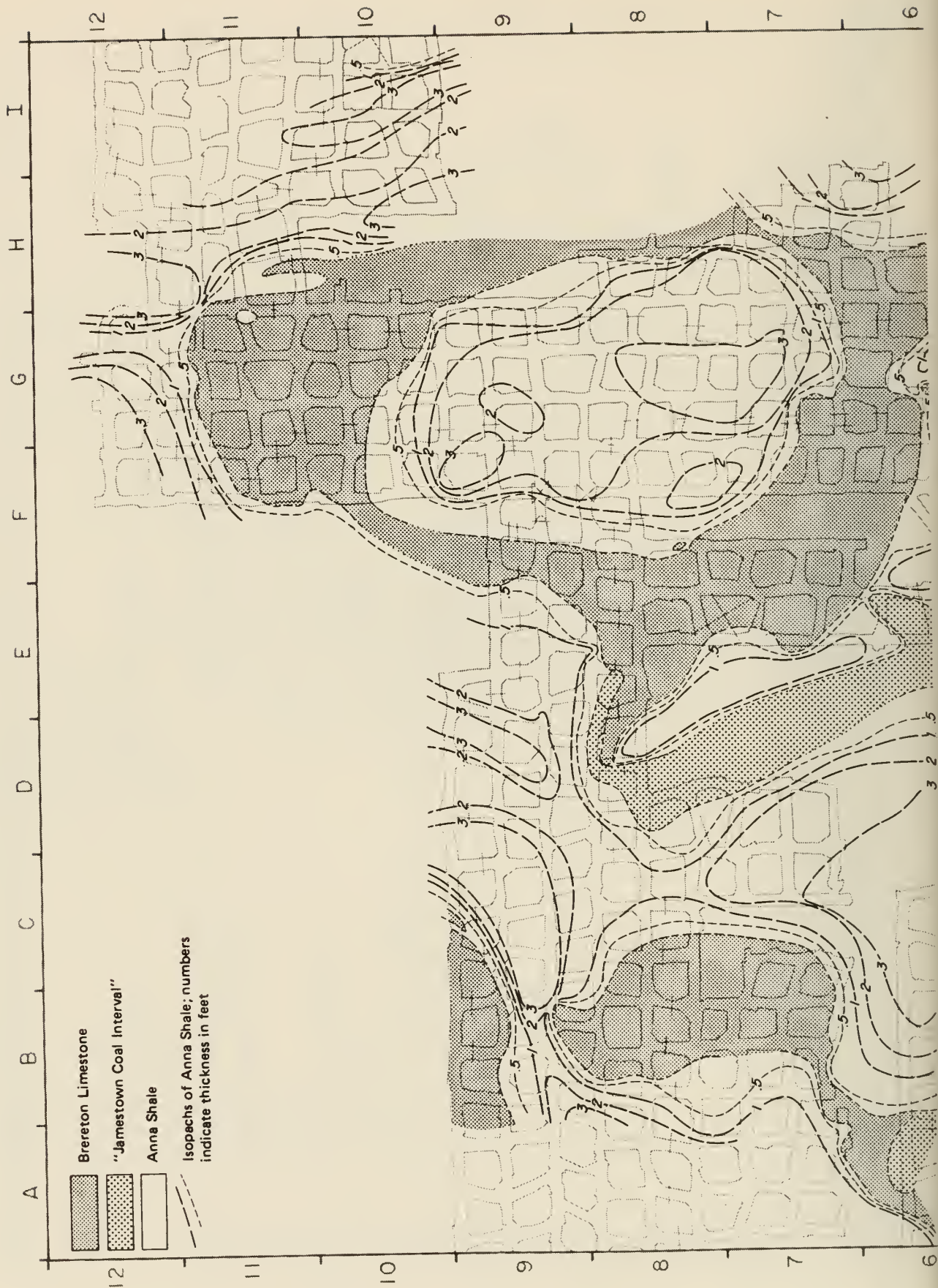


Figure 125. Lithologic data of the immediate roof strata of Herrin (No. 6) Coal in study area 2 of mine A. Areas of unstable roof provided more data than areas of stable roof.



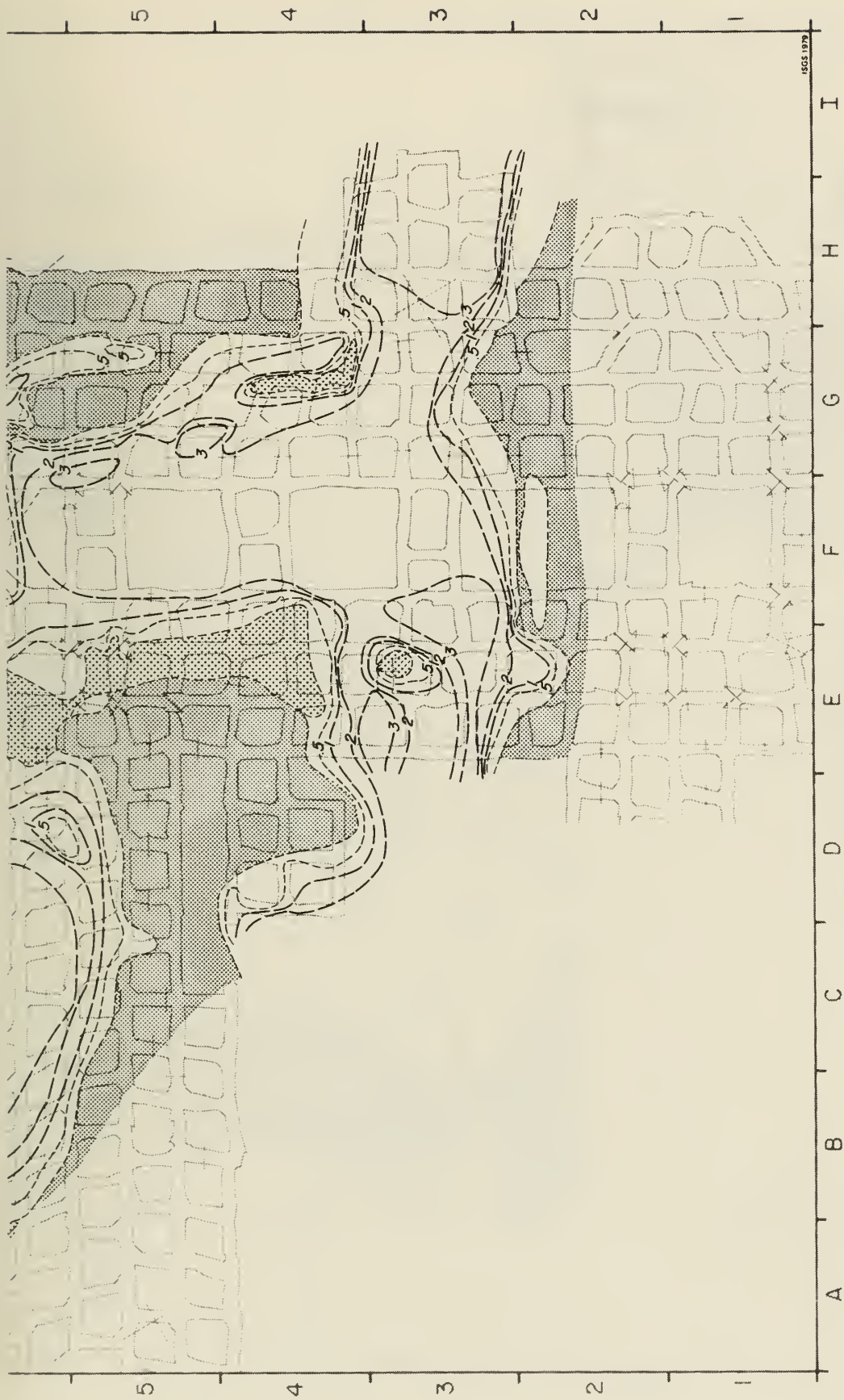
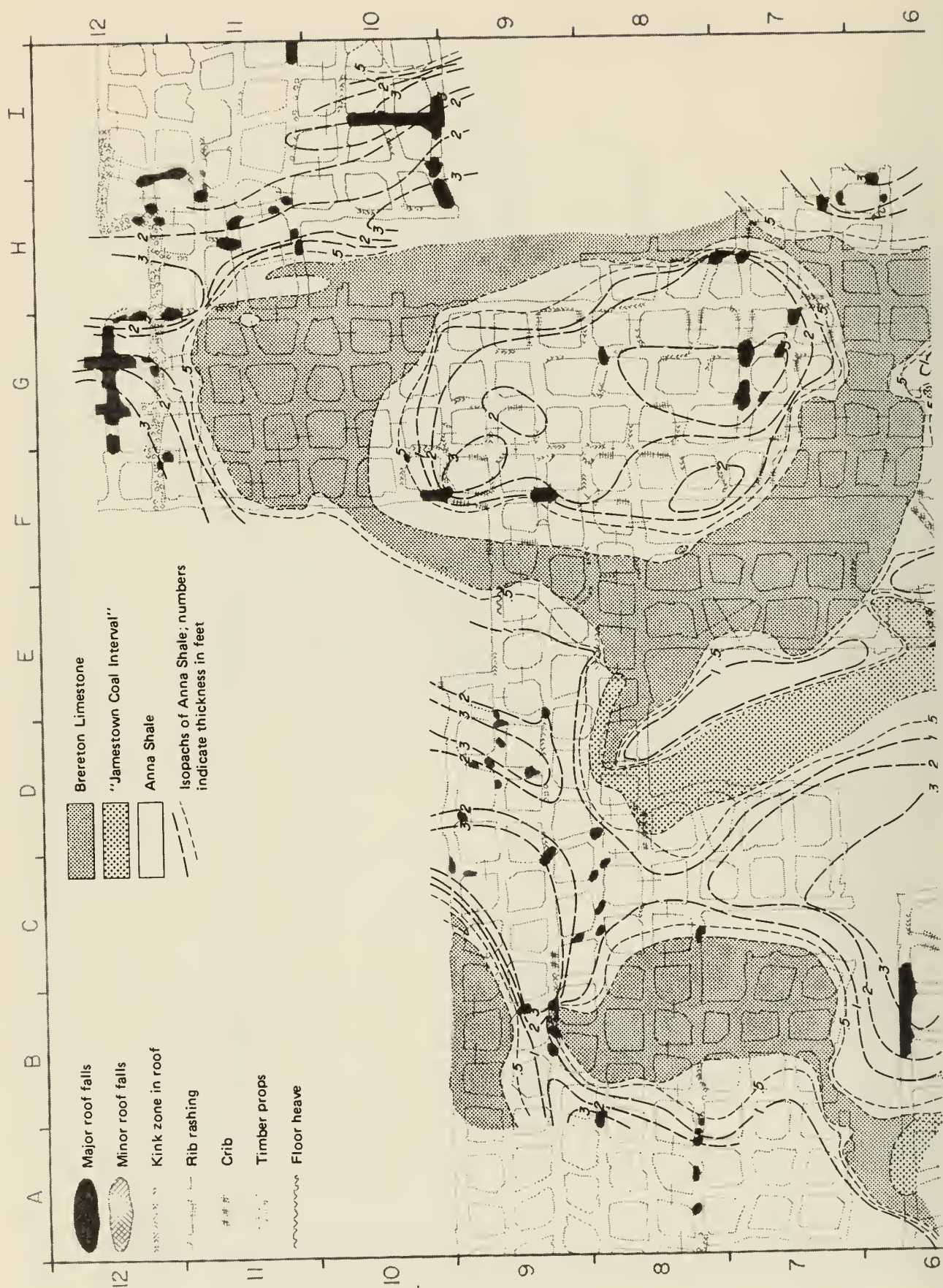


Figure 126. Lithology of the immediate roof strata of Herrin (No. 6) Coal and thickness of Anna Shale in study area 2 of mine A.



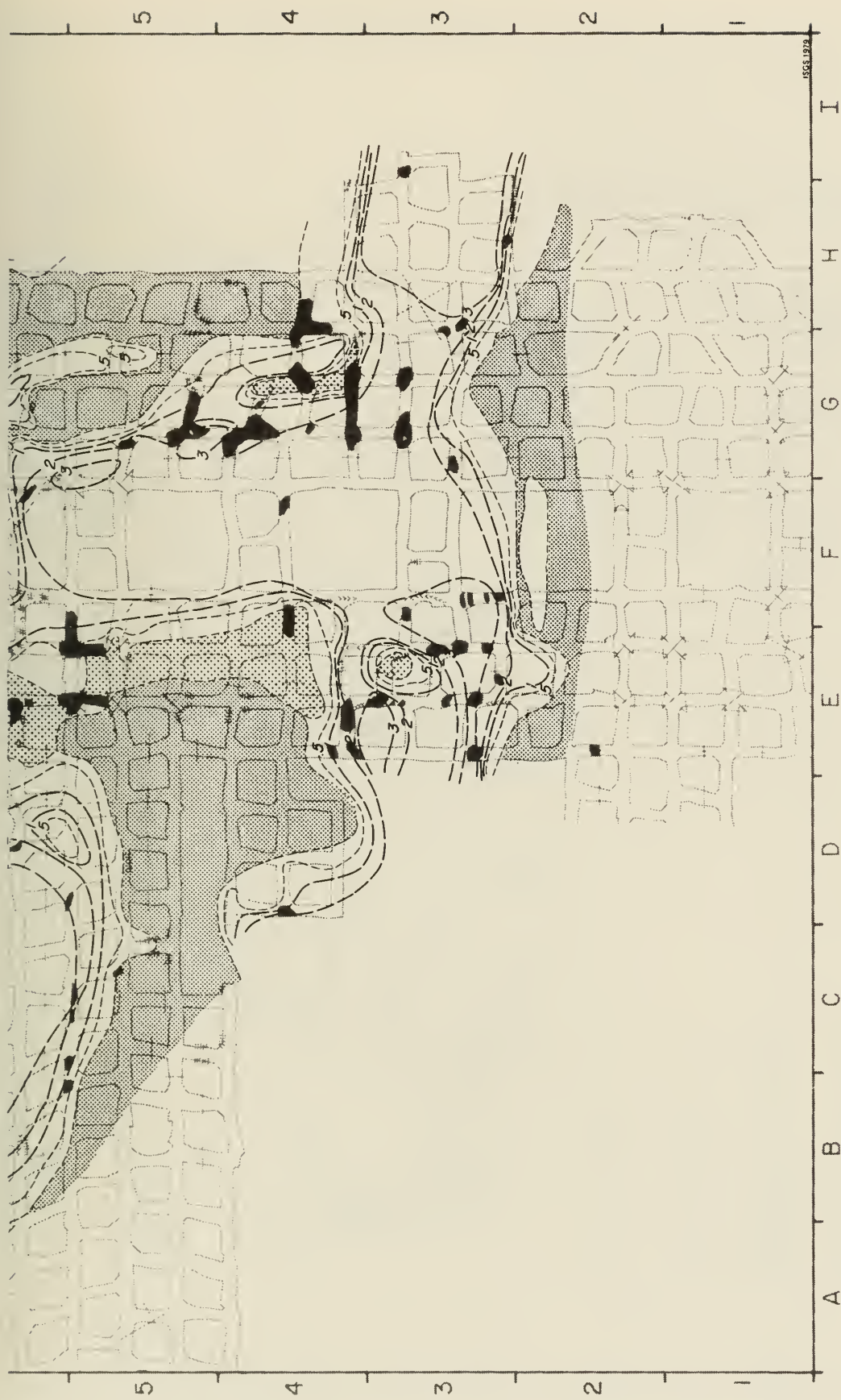
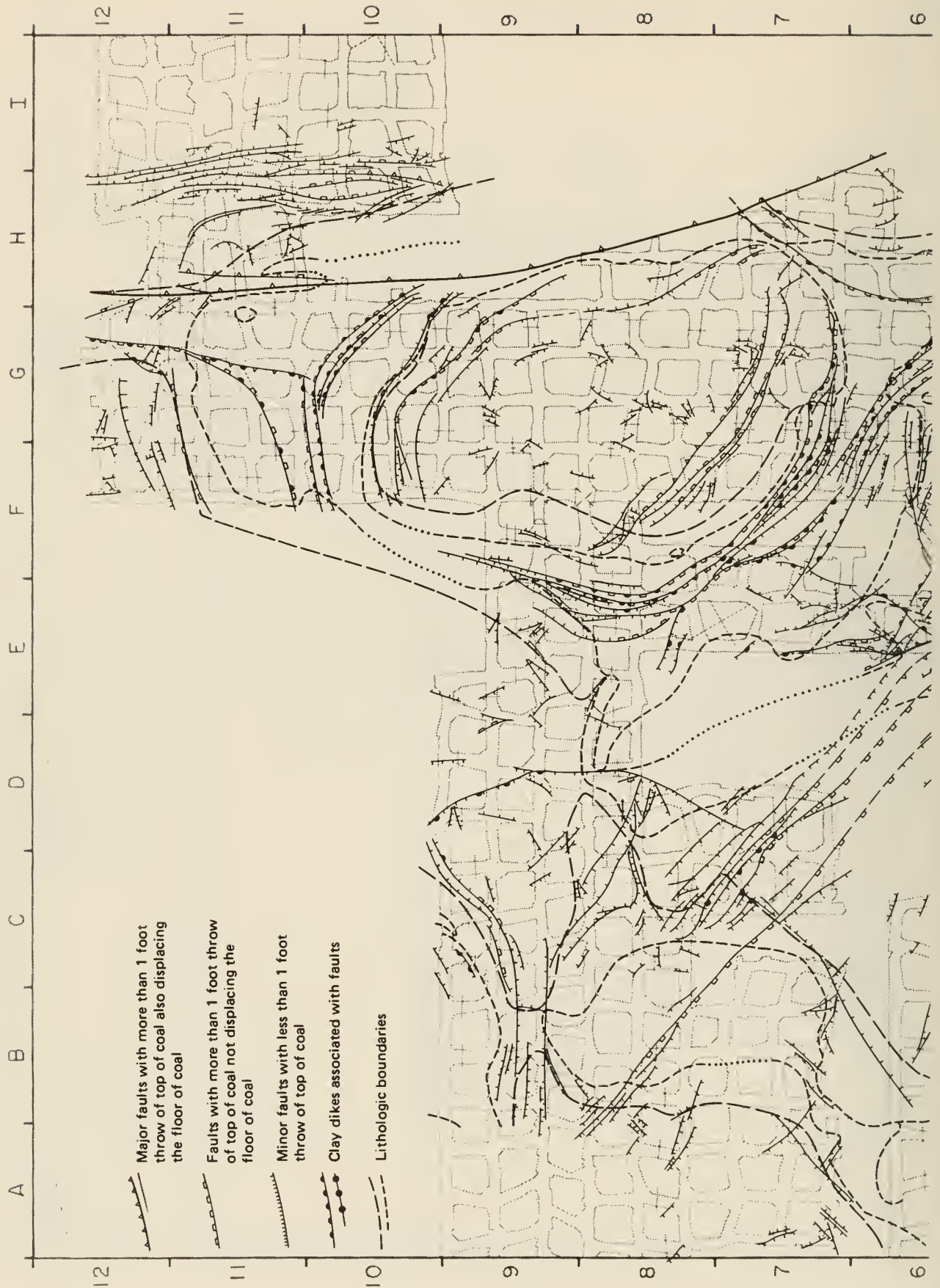


Figure 127. Distribution of roof falls and their relation to the immediate roof strata in study area 2 of mine A. No roof falls occur where Breerton Limestone directly overlies the Herrin (No. 6) Coal, although some shallow flaking of "clod" may occur locally.



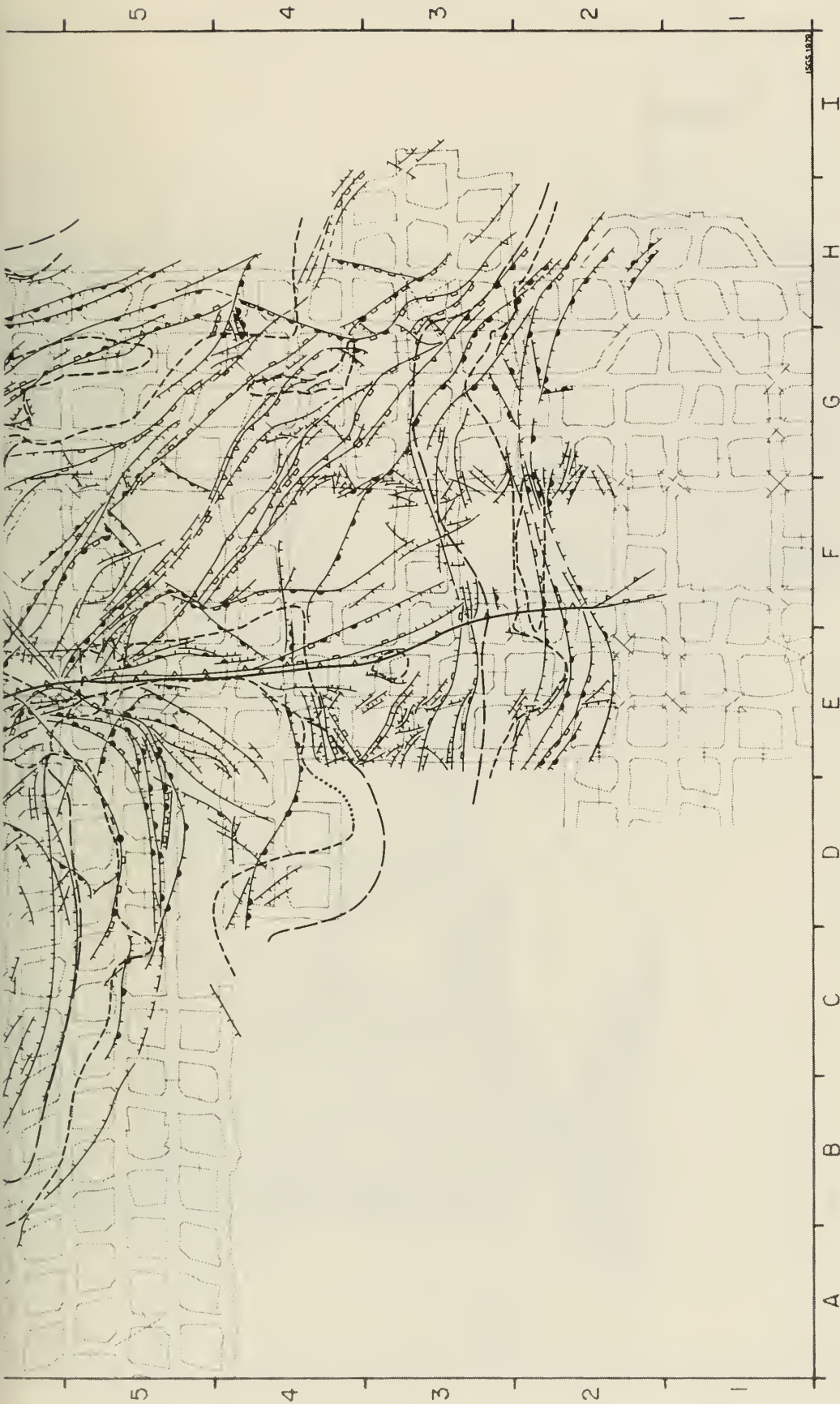


Figure 128. Clay-dike faults and clay dikes in Herrin (No. 6) Coal and its immediate roof strata in study area 2 of mine A. Position, orientation, distribution, and frequency of faults and clay dikes seem to have formed in close relationship to and are dependent upon the lithologic setting and facies distribution.

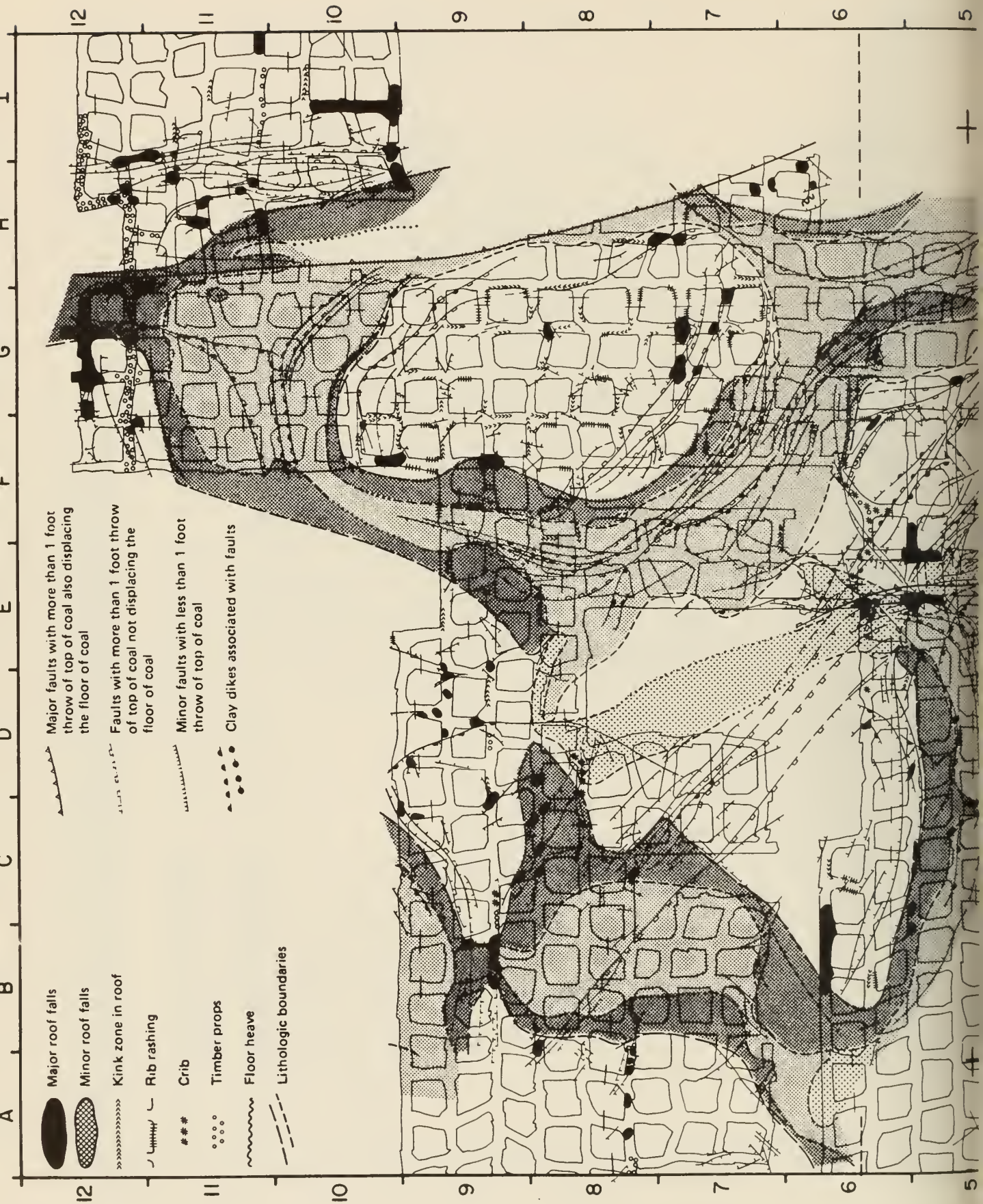




Figure 129. Distribution of lithology, of clay-dike faults and clay dikes in the Herrin (No. 6) Coal and its immediate roof strata, and of roof falls and other induced instabilities in study area 2, mine A. The occurrence of roof falls is a function of two geologic variables: (1) lithologic distribution and pattern of roof rocks and (2) structural setting and fault pattern. Roof falls are abundant along faults; however, there appears to be a greater affinity of roof falls to the lithology than to faults.



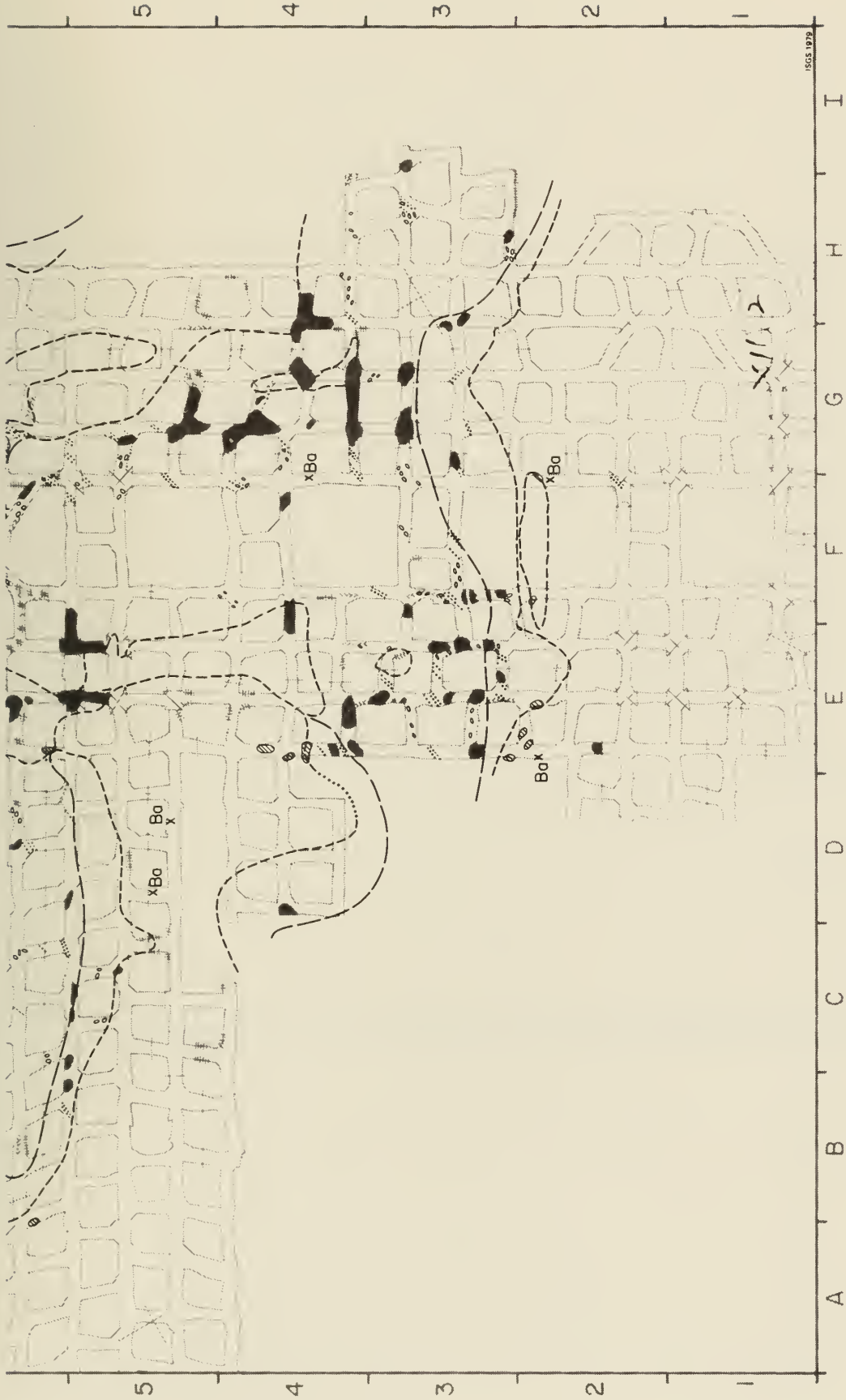


Figure 130. Distribution of additional data and lateral lithologic boundaries of the immediate roof strata of Herrin (No. 6) Coal in study area 2 of mine A.

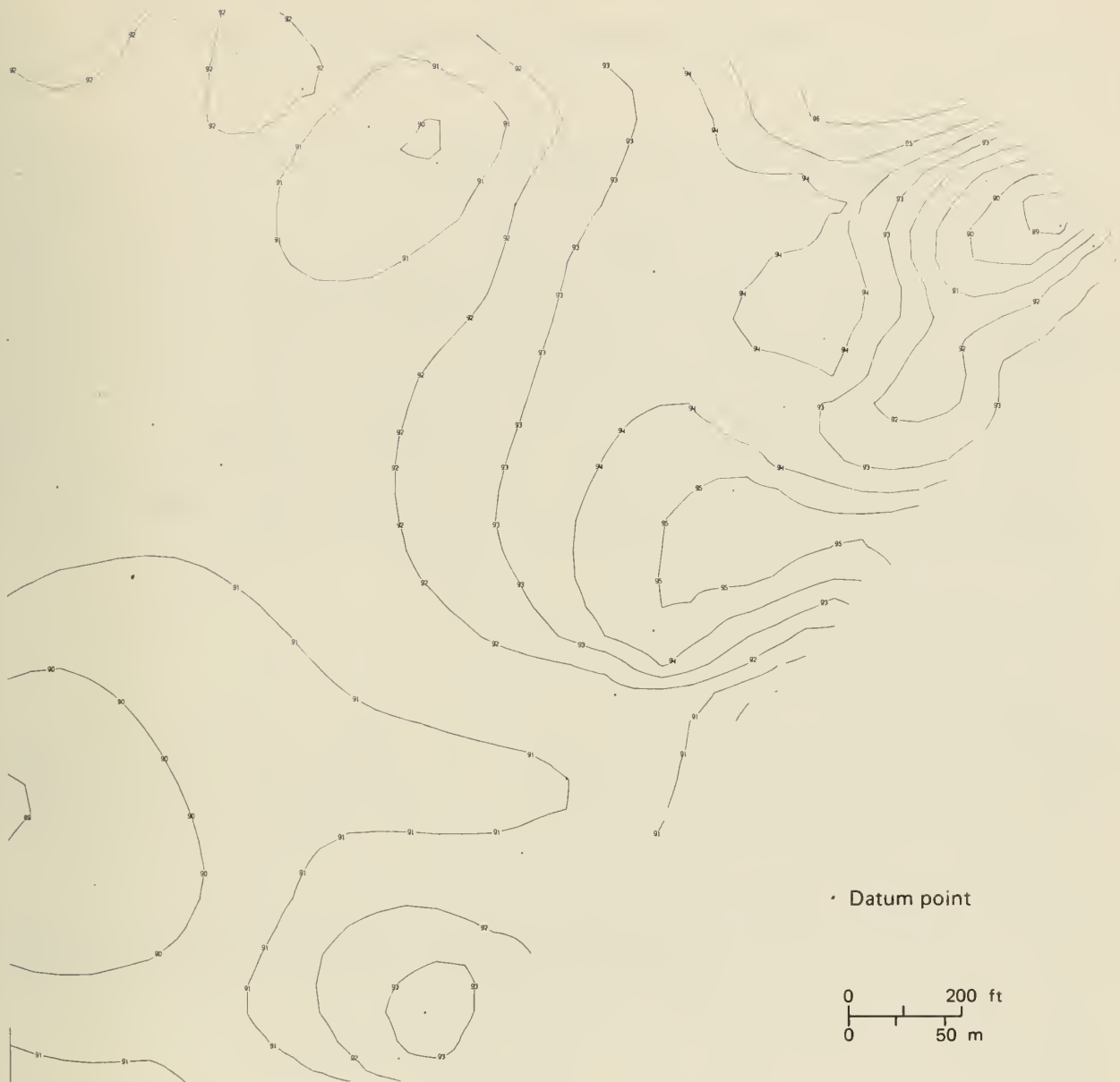


Figure 131. Map of the base of the Herrin (No. 6) Coal in study area 2 of mine A. The contour interval is one foot, and the grid size is 100 foot. Compare with figure 116; the difference in display of the contours results from the smaller contour interval and grid size.

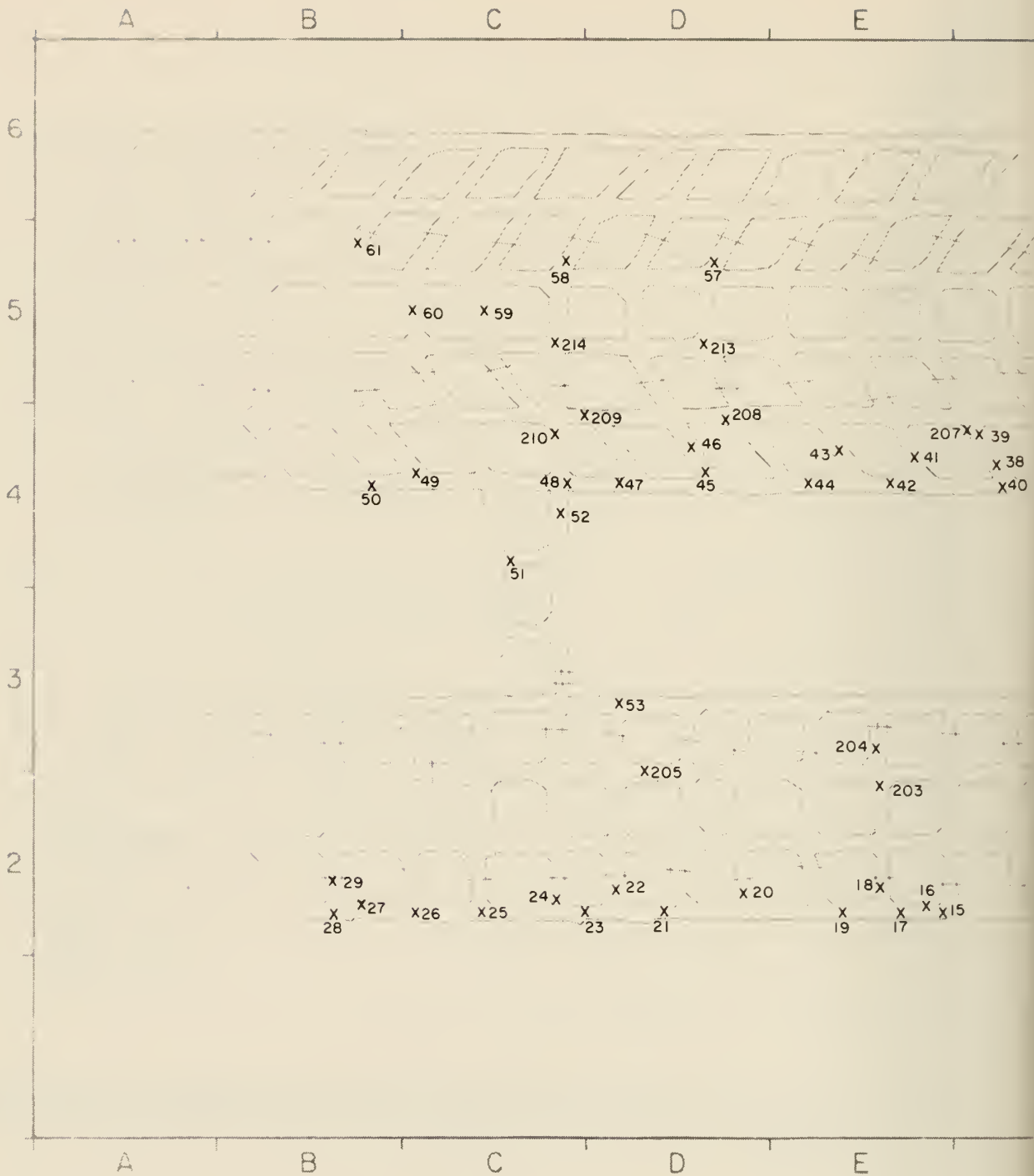
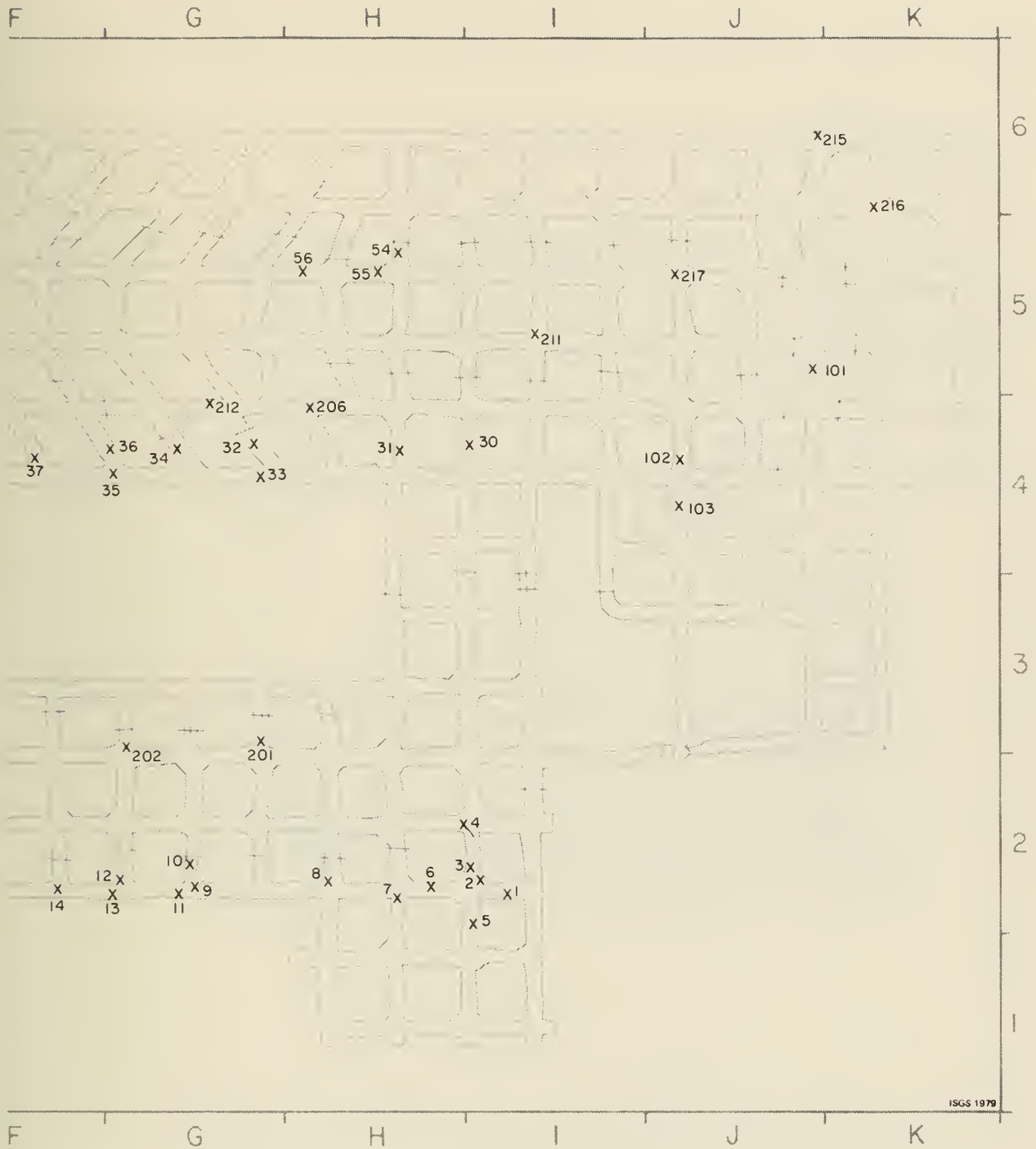


Figure 132. Stations in study area 3 of mine A, at which detailed studies were performed and notes were taken. The density of stations and data points allows evaluation of the confidence range for interpolation and interpretation. (Numbers on the map correspond to station numbers in ISGS mine notes.)



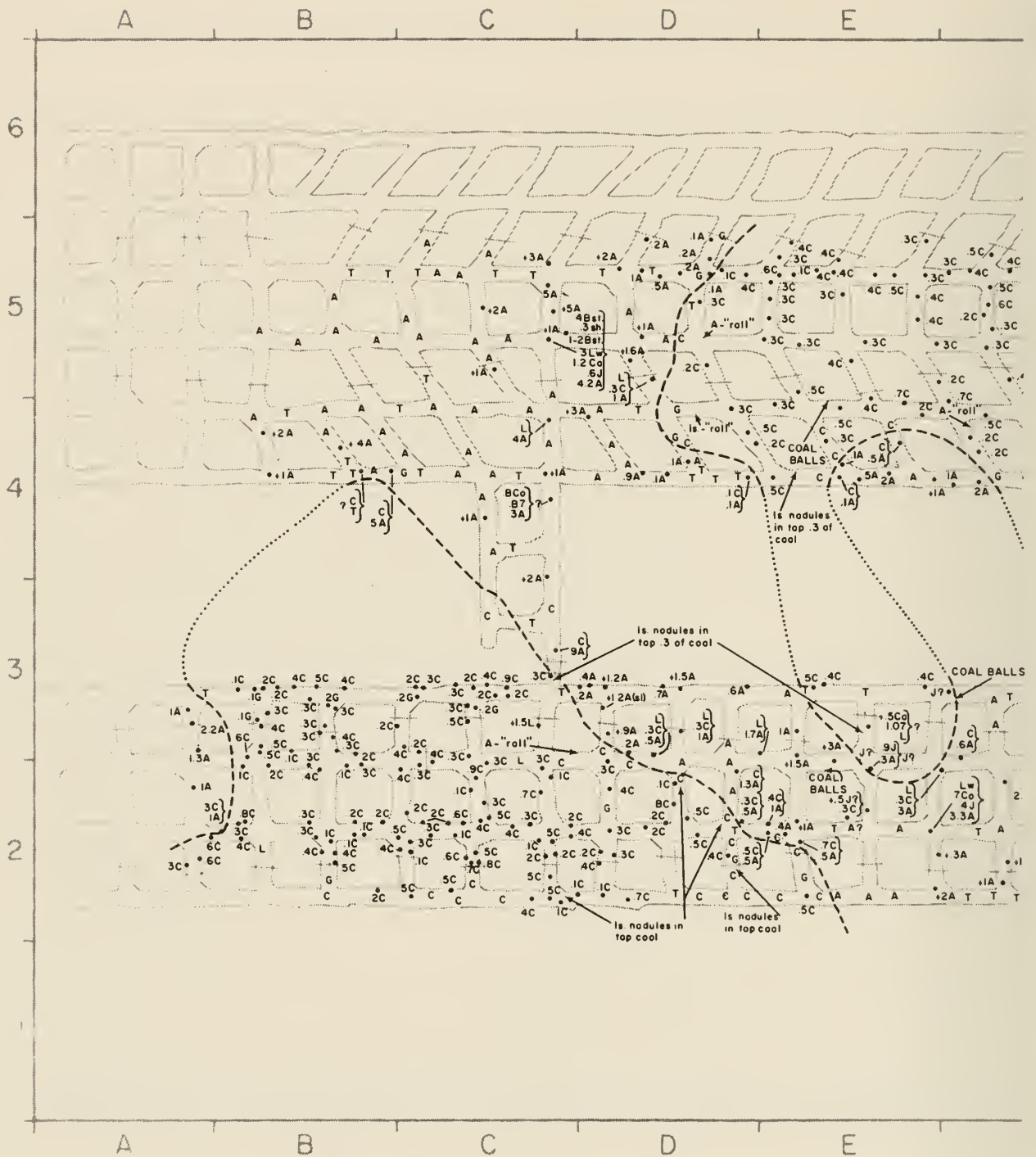
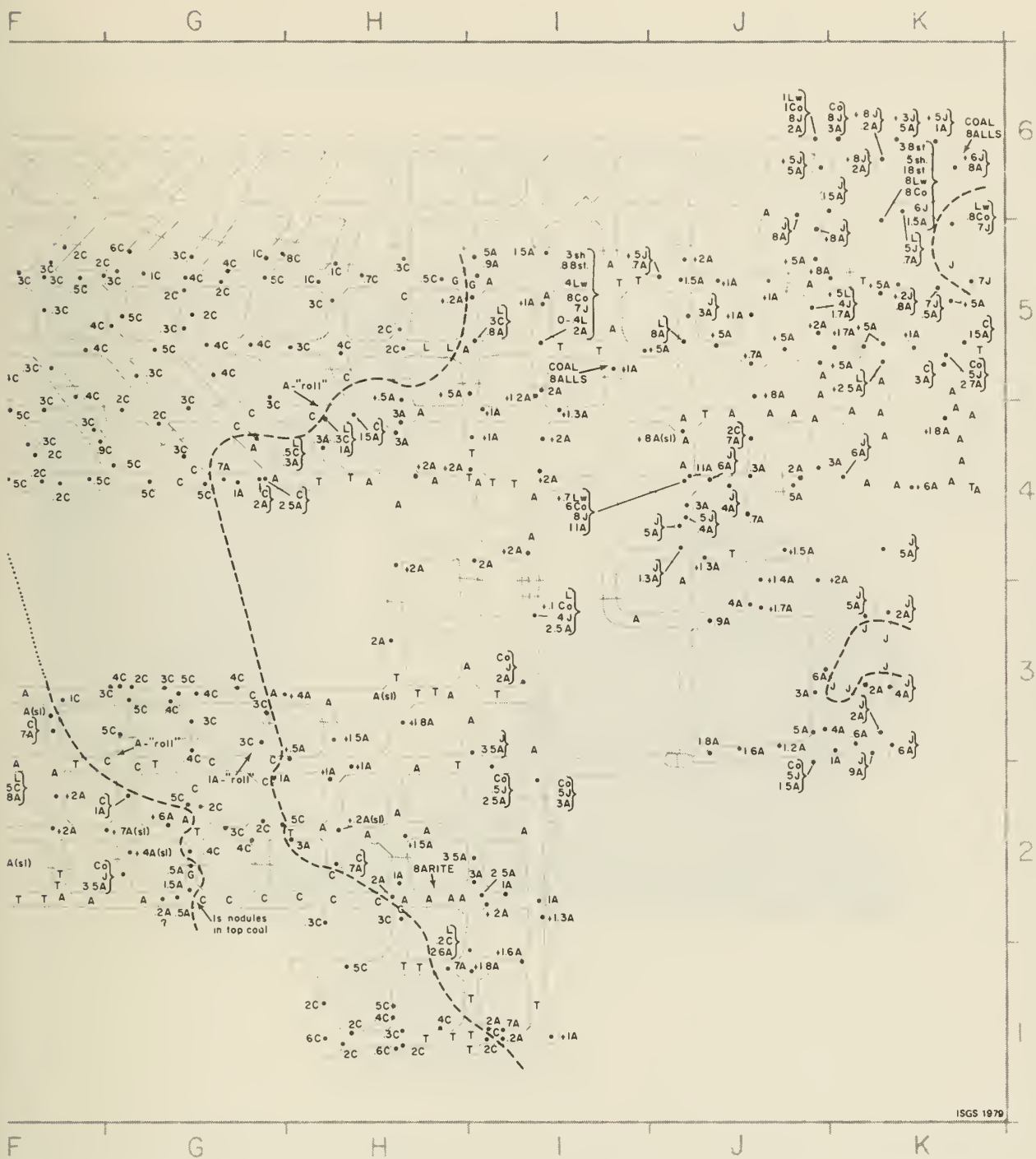


Figure 133. Lithologic data of the immediate roof strata of Herrin (No. 6) Coal in study area 3 of mine A. Areas of unstable roof provided more data than areas of stable roof.



ISGS 1979

Bkst	Bankston Fork Limestone	G	Limestone and coal intermixed due to bioturbation	15	Thickness in feet
LW	Lawson Shale			+	Total thickness exceeds measured thickness
Co	Conant Limestone	A	Anna Shale		
J	"Jamestown Coal interval"	A(sl)	Anna Shale, lower fissile portion		
L	Brereton Limestone	Bost	"Bastard limestone"		
C	"Clod" below Brereton Limestone	T	Top coal		
			---		Lithologic boundaries

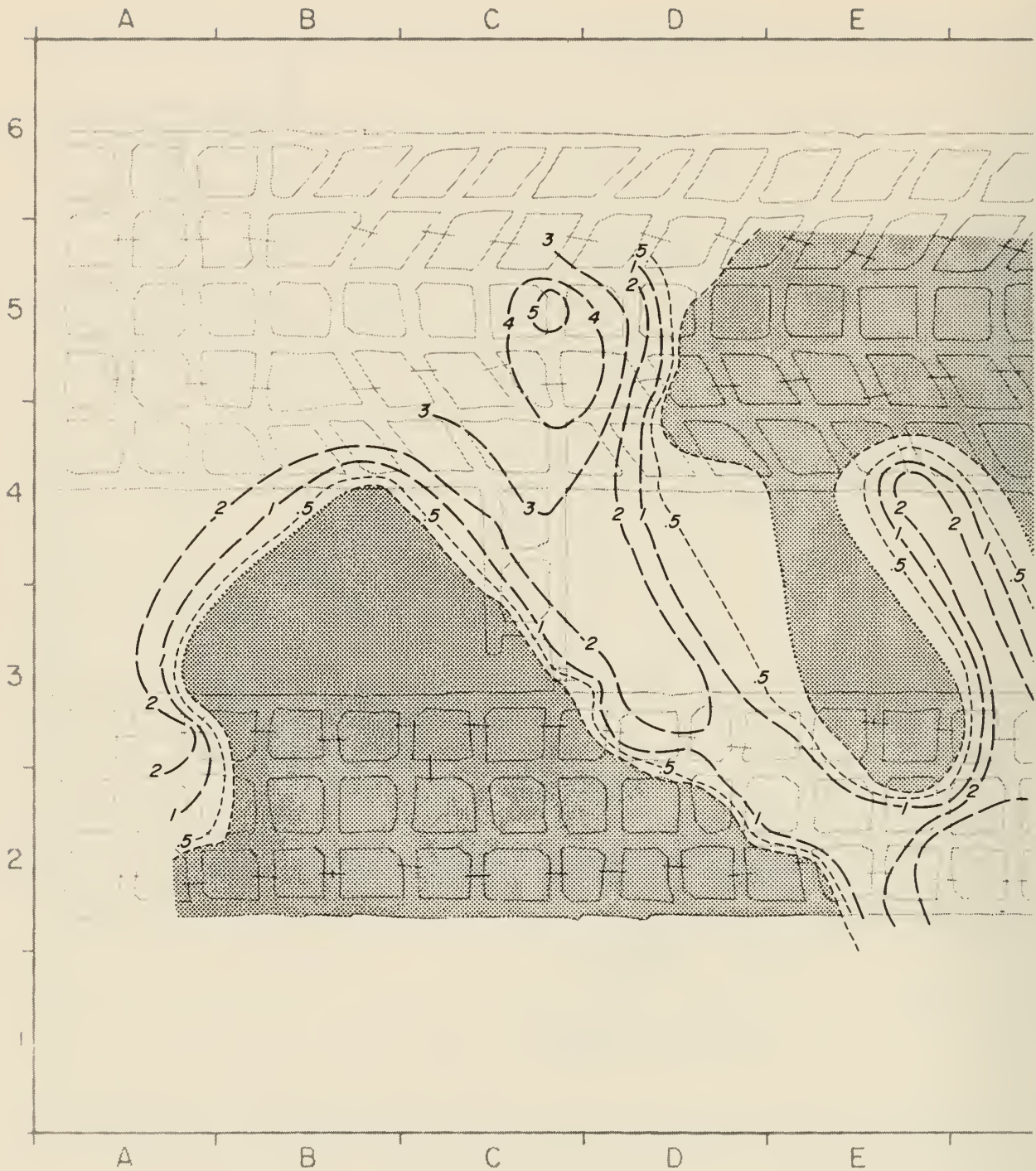
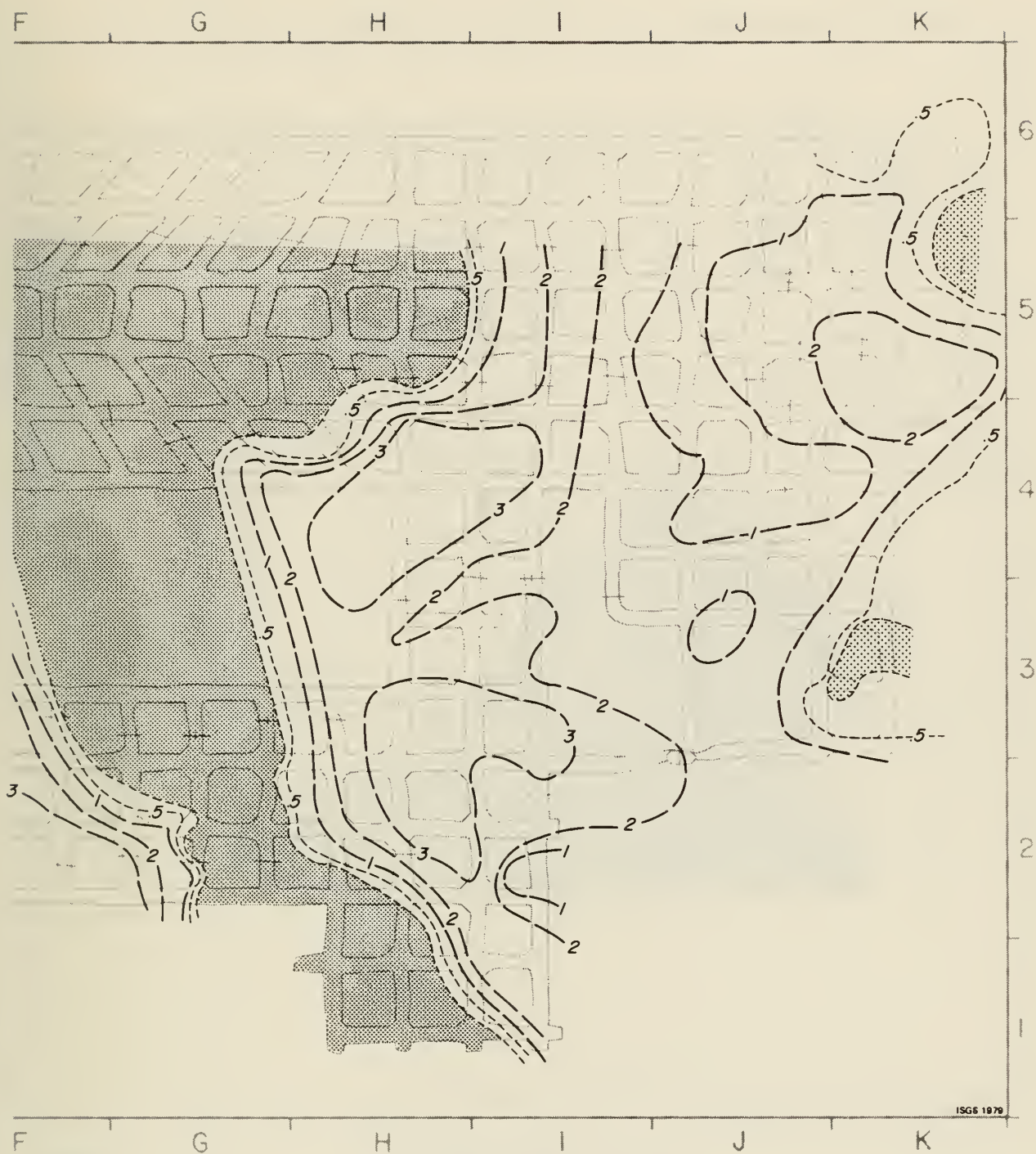






Figure 134. Lithology of the immediate roof strata of Herrin (No. 6) Coal and thickness of Anna Shale in study area 3 of mine A.



ISGS 1979

-  "Jamestown Coal interval"
-  Brereton Limestone
-  Anna Shale
-  Isopachs of Anna Shale; numbers indicate thickness in feet

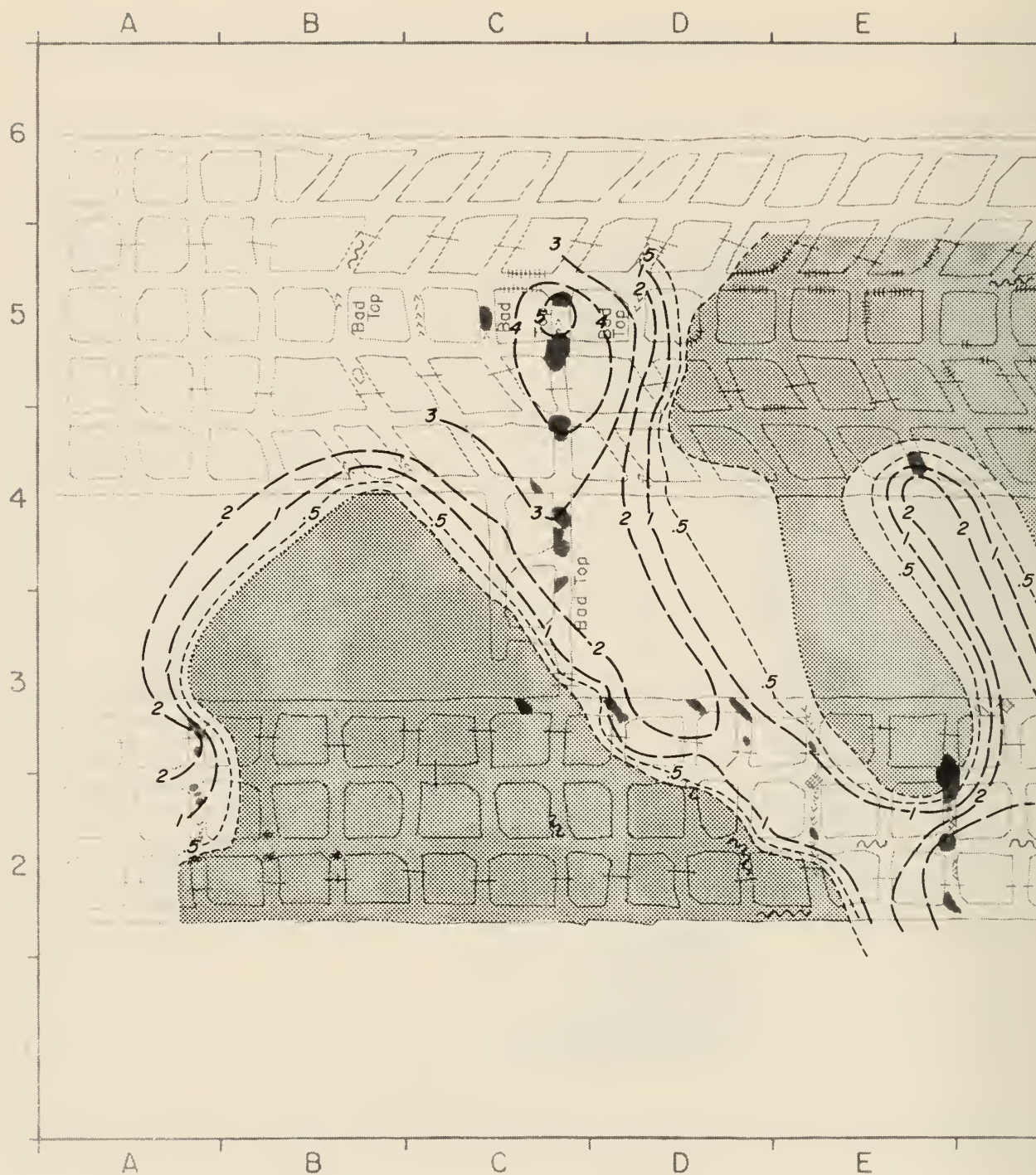
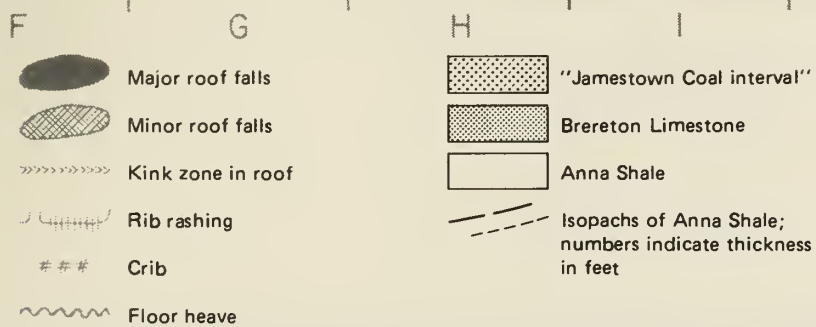


Figure 135. Distribution of roof falls and their relation to the immediate roof strata in study area 3 of mine A. No roof falls occur where Brereton Limestone directly overlies the Herrin (No. 6) Coal, although some shallow flaking of "clod" may occur locally.



ISGS 1976



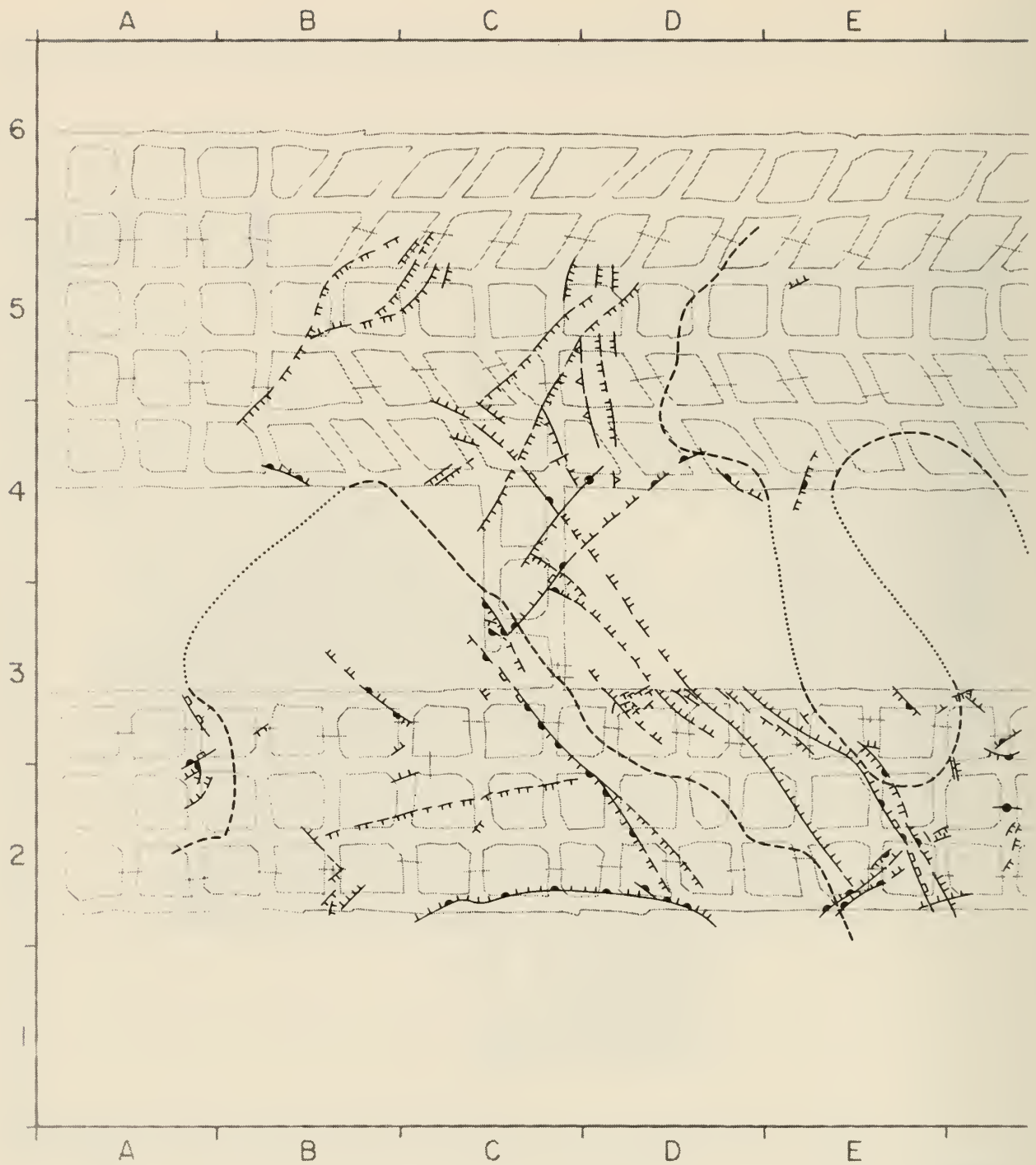
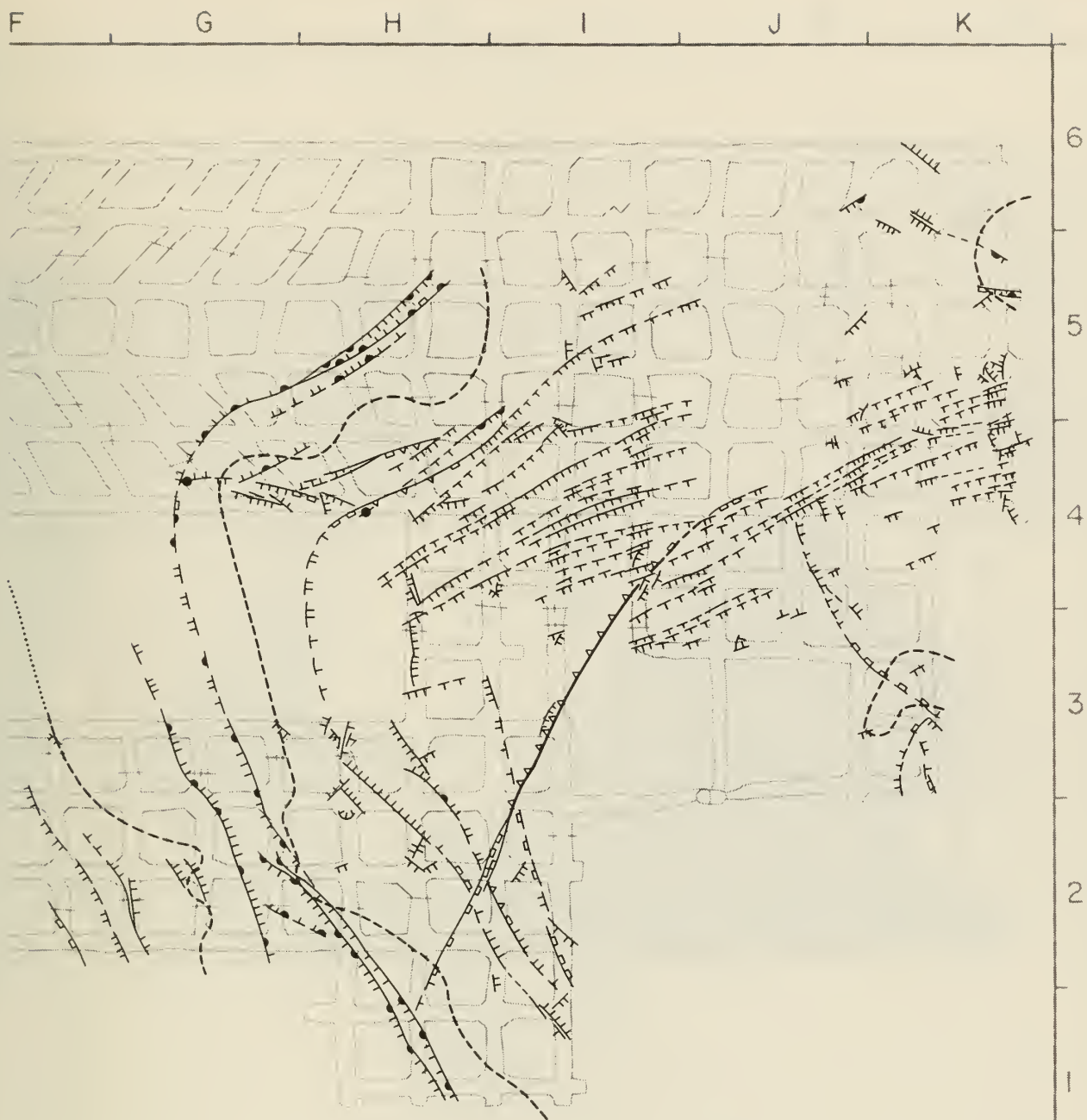
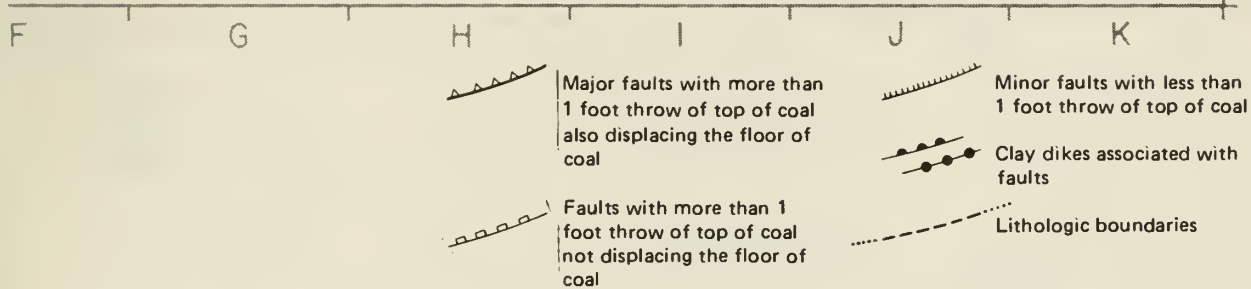


Figure 136. Clay-dike faults and clay dikes in Herrin (No. 6) Coal and its immediate roof strata in study area 3 of mine A. Position, orientation, distribution, and frequency of faults and clay dikes seem to have formed in close relationship to and are dependent upon the lithologic setting and facies distribution.



ISGS 1979



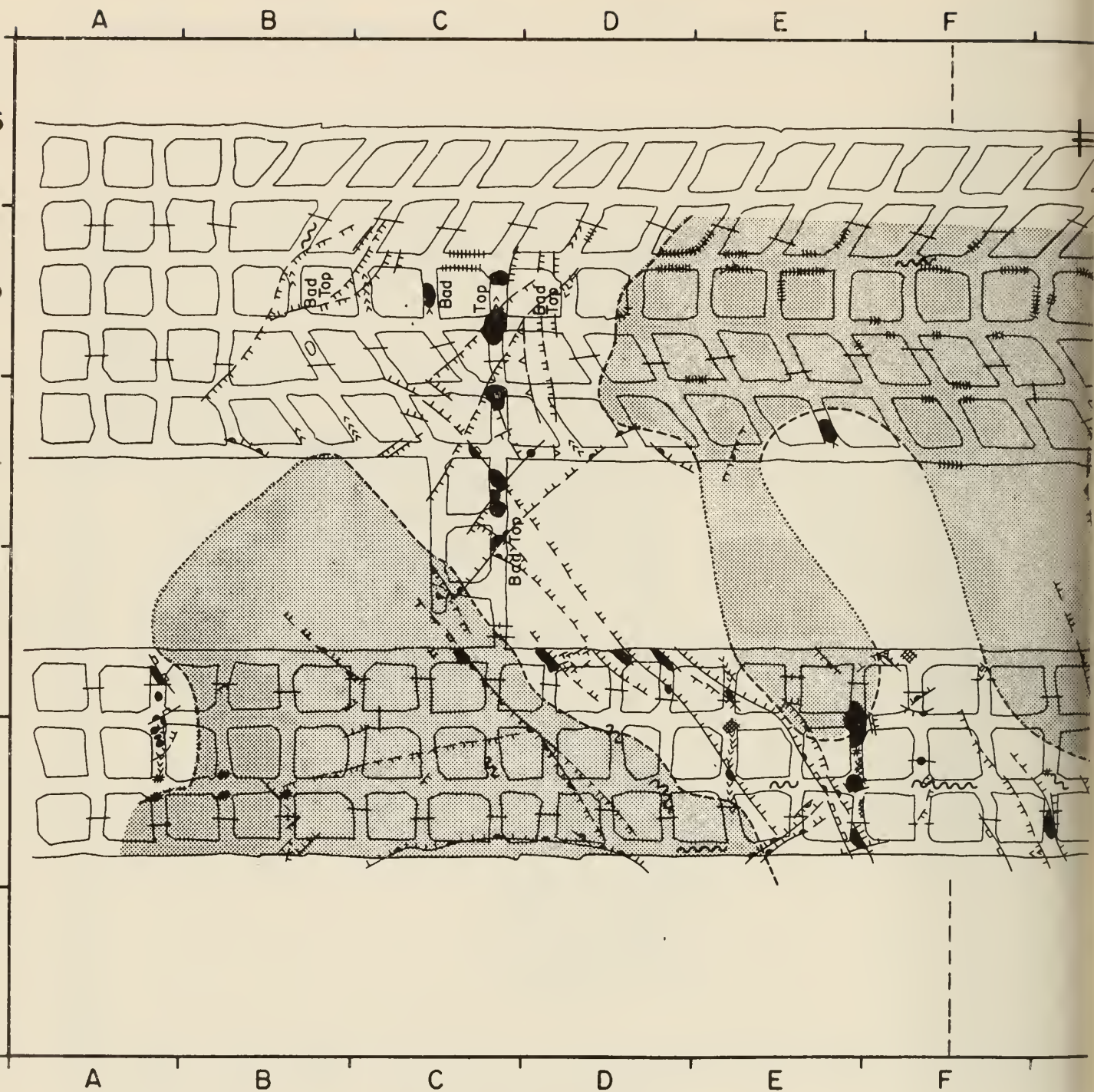
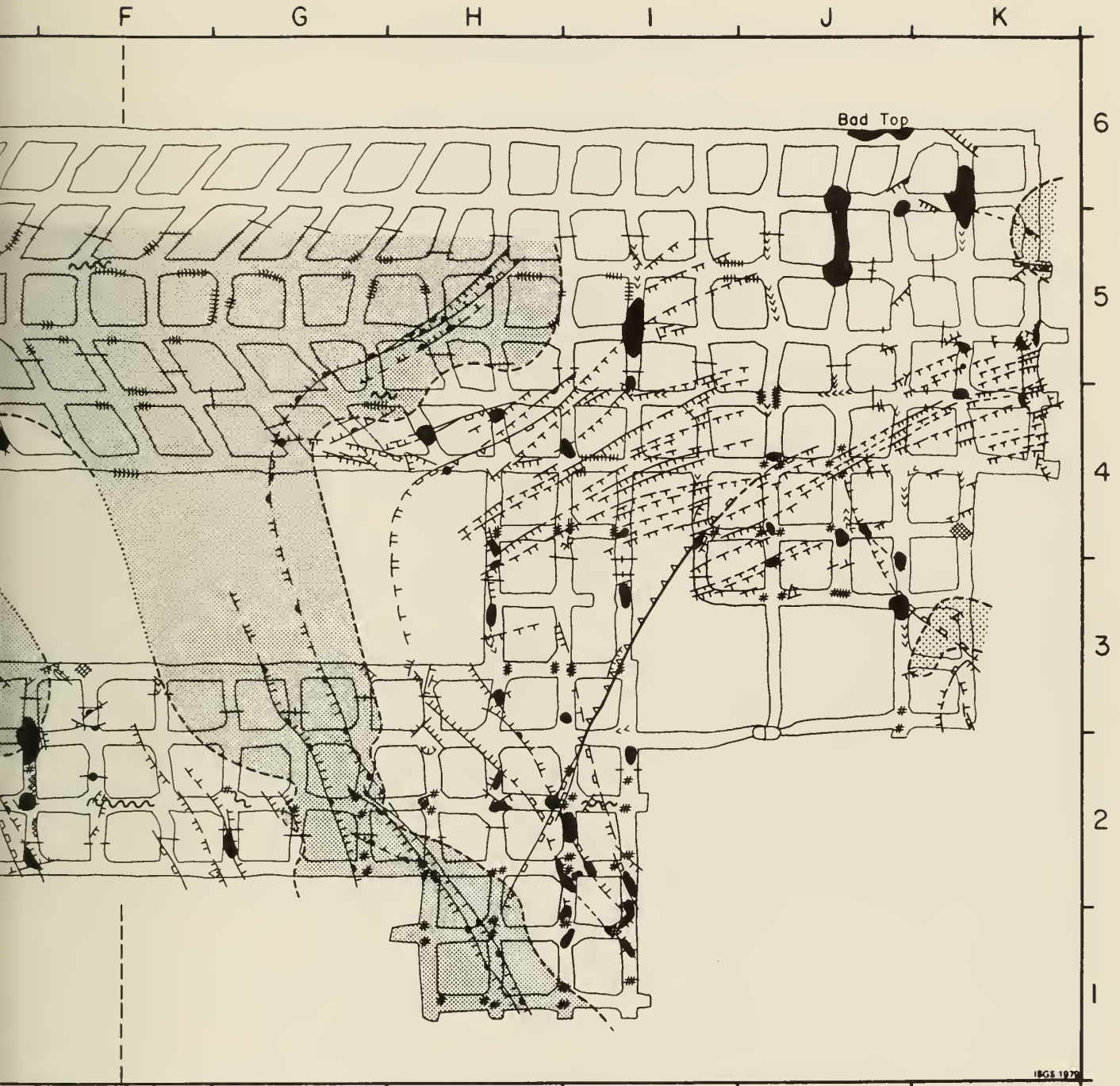


Figure 137. Distribution of faults and clay dikes in the Herrin (No. 6) Coal and its immediate roof strata and of roof falls and other induced instabilities in study area 3, mine A. The occurrence of roof falls is a function of two geologic variables: (1) lithologic distribution and pattern of roof rocks and (2) structural setting and fault pattern. Roof falls are abundant along faults and slips; however, there appears to be a greater affinity of roof falls to the lithology than to faults.



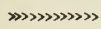
IBGS 1979



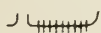
Major roof falls



Minor roof falls



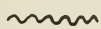
Kink zone in roof



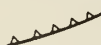
Rib rashing



Crib



Floor heave



Major faults with more than 1 foot throw of top of coal also displacing the floor of coal



Faults with more than 1 foot throw of top of coal not displacing the floor of coal



Minor faults with less than 1 foot throw of top of coal



Clay dikes associated with faults



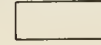
Lithologic boundaries



"Jamestown Coal interval"



Brereton Limestone



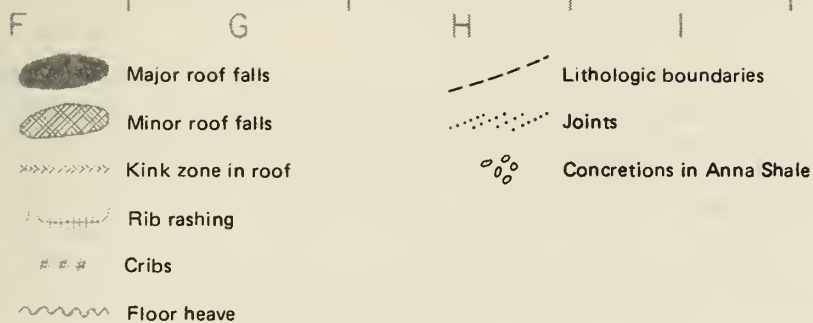
Anna Shale



Figure 138. Distribution of additional data and lateral lithologic boundaries of the immediate roof strata of Herrin (No. 6) Coal, study area 3 of mine A.



ISGS 1979



STUDY AREAS IN GRAY SHALE ROOF

The study areas 4 through 7 in mines having the gray shale type of roof were selected with respect to differences in facies and roof behavior. The stability of the roof in study area 4 can be demonstrated with one map (fig. 139), which shows the distribution of two lithologic facies of the Energy Shale—the lower dark-gray shale facies and the upper medium-gray shale facies as described in detail in the previous chapter. The map also displays the abundance of rolls and minor faults in the medium-gray shale and their absence in the dark-gray shale.

Roof falls are scarce and commonly shallow with the exception of the major fall in areas E/4 and E/5. None of the roof falls indicates a major relationship to lithologic change or to structural features; however, an abundance of kink zones (zones of bending or sagging in the immediate roof) was found. The strike of these kink zones is generally north-south or slightly west of north (fig. 58). The kink zones develop some time after mining, and their relationship with geological structure is not yet known.

The geology and roof stability of study area 4 contrast sharply with those found in study area 5 (figs. 140-143). The distribution of the two facies composed of dark-gray shale and medium- to light-gray shale is displayed, but appears to be much more irregular than in area 4. The relationship of the early diagenetic deformational features (rolls and small faults), which are in many cases connected with the rolls, is more apparent and also demonstrates the correlation between lithology and structural features. The rolls and their associated structural elements are more or less restricted to the medium-gray shale (just as clay dikes are restricted to areas of Brereton Limestone roof). The rolls and associated faults trend parallel to the lateral boundaries of the dark-gray shale. The abundant roof falls reach a height of 15 to 20 feet (4.5 to 6 m). They are dominant in, but not restricted to, the dark-gray shale (fig. 140). To avoid overcrowding the map, several very shallow roof falls caused by slabbing of immediate roof rock layers have not been included.

The distribution and density of the roof falls in study area 5 of mine B can be better understood by studying the map of the landslide shear body, figure 141. The lithologic distribution pattern is known from figure 140. In this map, the major traces of the low-angle shear surface and the outline of the entire landslide shear body as it forms the coal roof has been displayed. The interrelationship between the shear body, as described in the previous chapter, and the density of roof falls is demonstrated. Most of the roof falls were caused by the instability of the shear body, which contains numerous subhorizontal or low-angle shear surfaces.

The anomalies in the roof rock also have had significant effect on the coal or vice versa. They are reflected in figures 142 and 143. Two trends can be recognized in figure 143. The general north-south trend is dominated by a local east-west trend of the structural highs and lows (ridges and troughs). The genetic relation between the trends of lithologic bodies and structural features in the roof rock and the trends of coal structure is not yet known; however, similarity of trends of older sedimentary and early diagenetic features (shape and orientation of rock bodies) and younger deformational features (orientation of shear body) and trends in structural contours seems to be obvious. In-

terference patterns occur in both trends of coal structural contours and in trends of sedimentary and deformational features.

Study areas 6 and 7 in mine C were selected for mapping, at the invitation of the coal company, because of severe problems in roof control. The locations of the study areas are shown in figure 144, which also shows how abruptly the elevation of the top of the coal can change. Local changes in elevation are often the location of roof falls. A later chapter contains results of tests of the strength of roof rock from areas 6 and 7.

Study area 6 (fig. 145) has a laminated siltstone and sandstone roof that is generally stable; however, above the siltstone roof a water-bearing sandstone is found along narrow zones. This sandstone probably fills a small tributary or distributary of the nearby Walshville channel in the west. When the sandstone is about 20 feet or less above the top of the excavation, the roof commonly does not remain stable because of the poor slake durability of the argillaceous laminated siltstone. A "drip line" showing wet and dry conditions shown on the map nearly delineates the area of severe roof instability. Figure 146 displays the development of roof falls in intervals of several months.

Lithologic and water conditions in study area 7 (figs. 147 and 148) were similar to those in area 6. In addition, the roof of area 7 was characterized by numerous rolls and associated faults as well as other soft-sediment deformational features. The "mega-roll" shown in figure 148 was large enough to force alteration of mining plans in the panel.

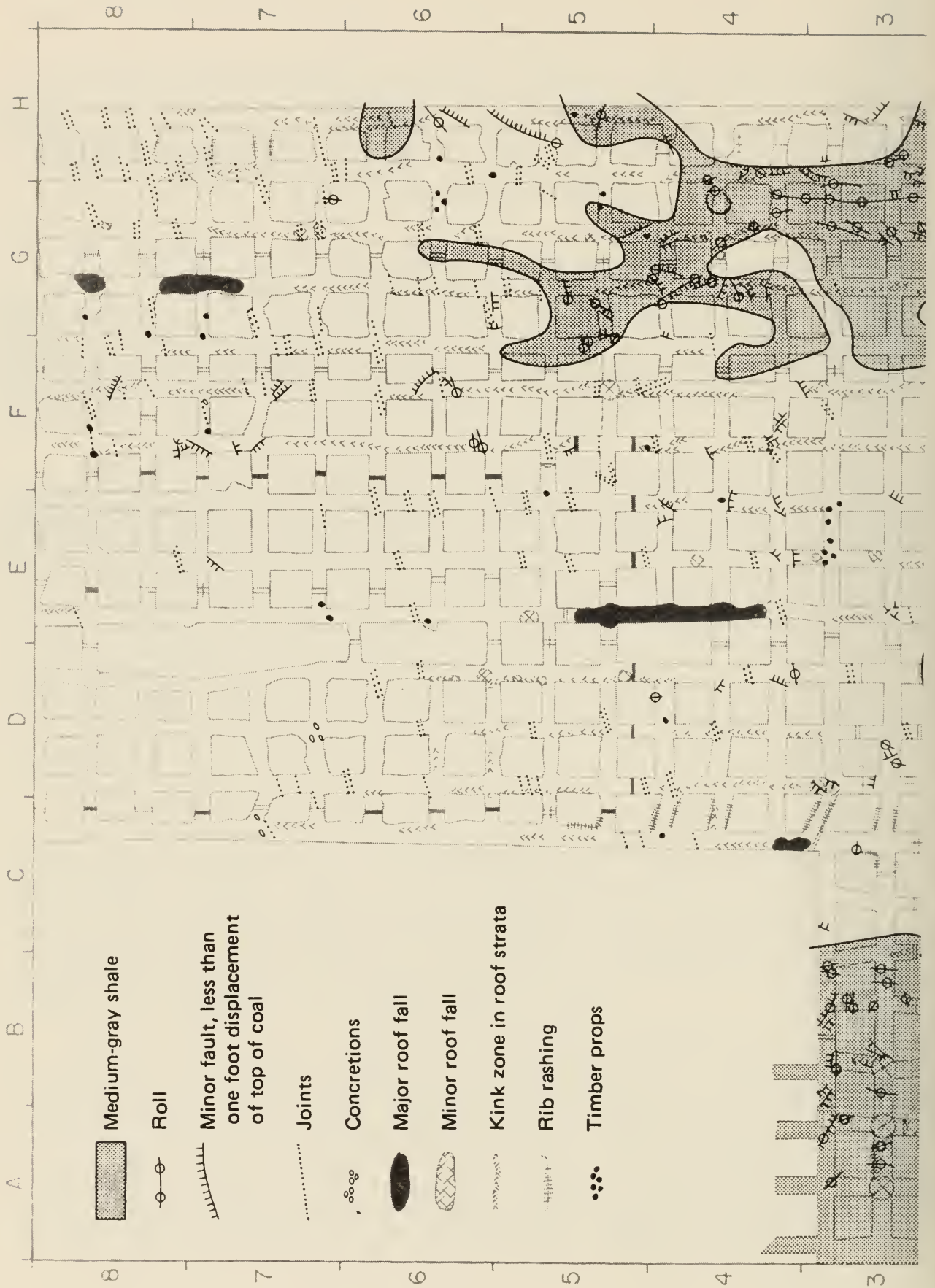
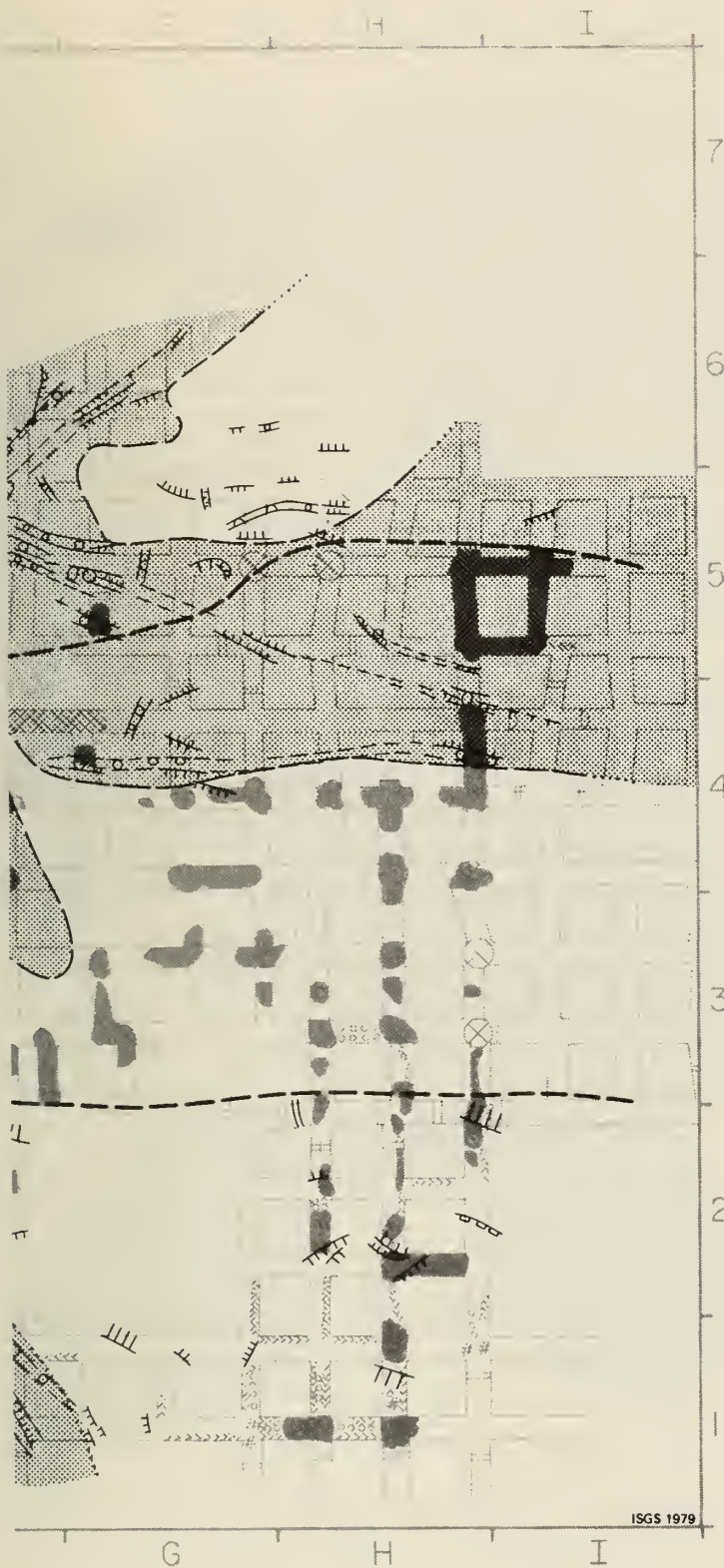




Figure 139. Lithology, structural features, roof falls, and additional data on the Herrin (No. 6) Coal and its immediate roof rocks in study area 4 of mine B. Immediate roof strata are Energy Shale, lower portion (not stippled) dark-gray shale and upper portion (stippled) medium-gray shale. The majority of rolls and faults occurs in medium-gray shale, whereas all roof falls and other features of instability (e.g., kink zones, and rib rashing) except one are distributed in areas of dark-gray shale. Jointing is also much more prominent in the well-bedded dark-gray shale.



Figure 140. Distribution of soft-sediment rolls associated with minor faults in relation to the lithology of the immediate roof and roof falls of Herrin (No. 6) Coal in study area 5 of mine B. The map displays the close interdependence of soft-sediment structural features, mainly rolls and slips, with distribution and lateral boundaries of the Energy Shale roof strata. Although the immediate roof in areas of medium-gray shale with rolls and slips commonly is very rough and irregular, the roof falls are more abundant in areas of dark-gray shale. Roof falls in areas of medium-gray shale occur mainly within the shear body.





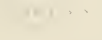

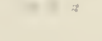
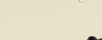

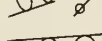
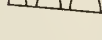


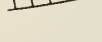


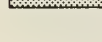
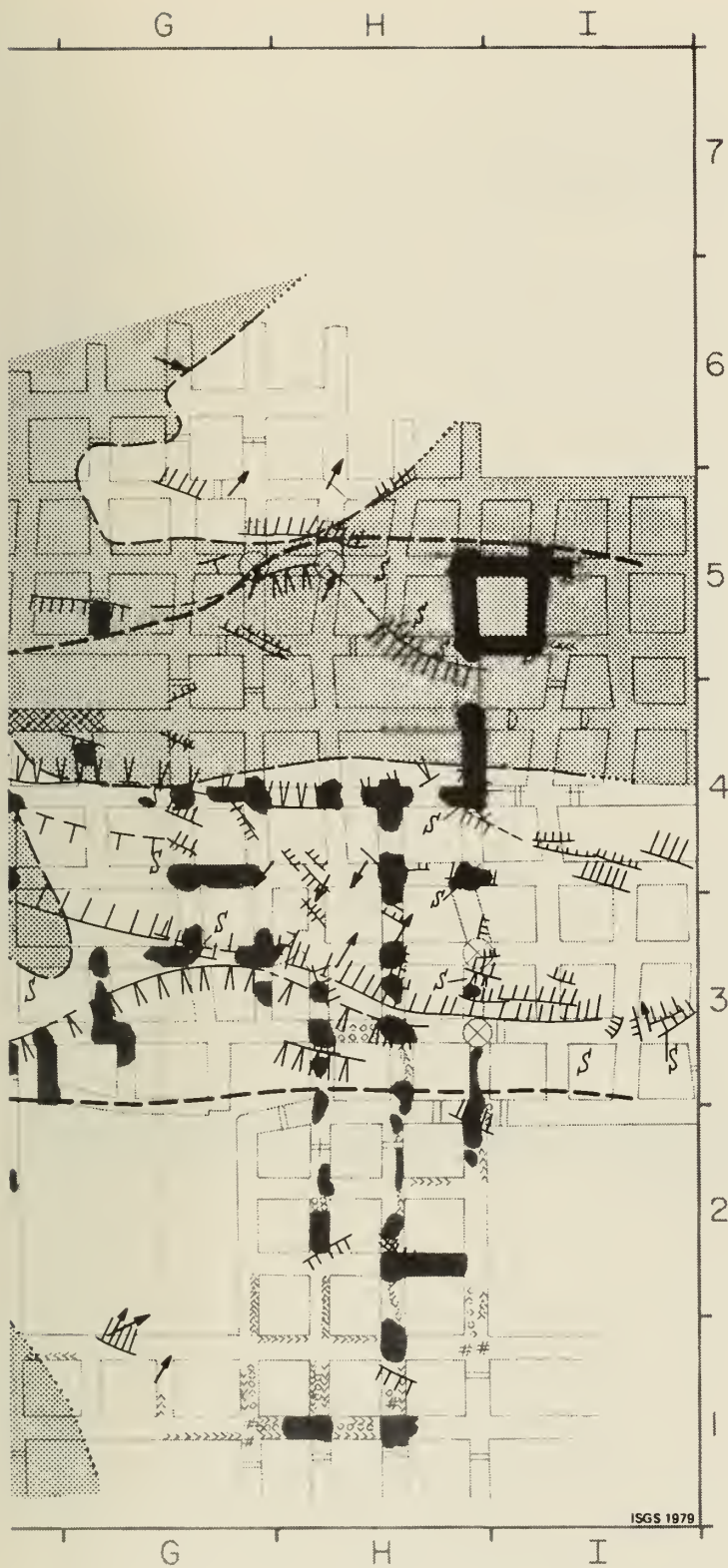


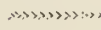
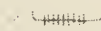
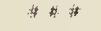

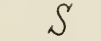
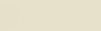

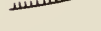

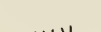

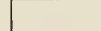

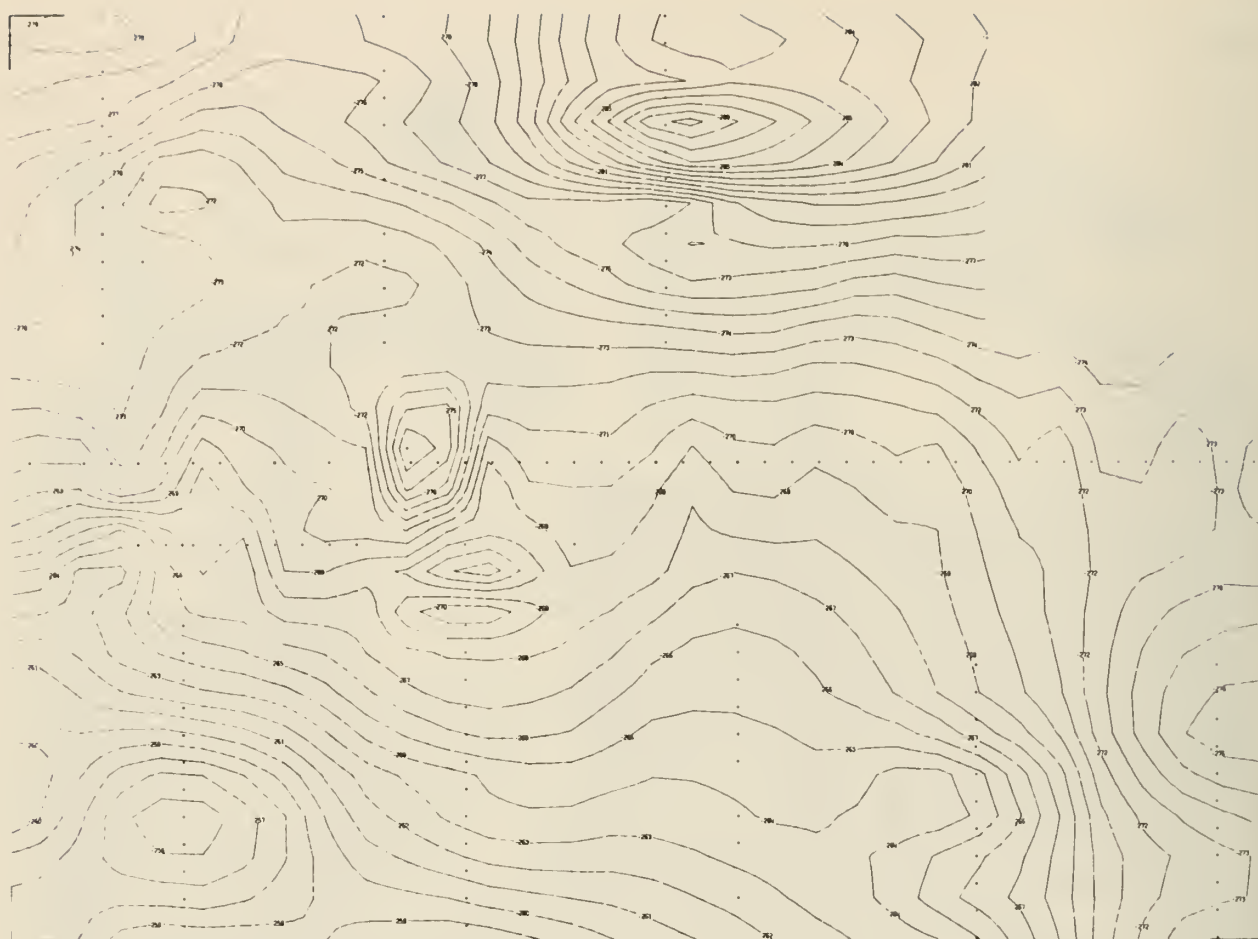
-  Major roof fall
-  Minor roof fall
-  Kink zone in roof
-  Rib rashing
-  Crib
-  Timber props
-  Clay dike
-  Symmetrical roll
-  Asymmetrical roll (tail at open end of semicircle)
-  Shear plane—high angle (minor fault)
-  Shear plane—low angle (minor fault)
-  Well-bedded dark-gray shale, lower portion of Energy Shale
-  Poorly bedded medium-gray shale, upper portion of Energy Shale
-  Boundary between rock units
-  Boundary of shear body



Figure 141. Outline and major shear structures of the shear body in study area 5 of mine B. Roof falls have occurred most often in the area of the shear body and to a lesser degree under dark-gray shale in the immediate vicinity of the shear body. Deformational features older than the shear body have not been drawn on this map, but can be compared in their interrelationship to lithologic differences in figure 140. The shear body is not restricted to a particular lithology, but affects dark-gray shale and medium-gray shale and, locally, the top of the Herrin (No. 6) Coal as well.



-  Major roof fall
-  Minor roof fall
-  Kink zone in roof
-  Rib rashing
-  Crib
-  Timber props
-  Intensely sheared area with dense spacing of numerous small shear planes
-  Direction of striations
-  Shear plane—high angle (minor fault)
-  Shear plane—low angle (minor fault)
-  Multiple major shear planes within shear body
-  Well-bedded dark-gray shale, lower portion of Energy Shale
-  Poorly bedded medium-gray shale, upper portion of Energy Shale
-  Boundary between rock units
-  Boundary of shear body



• Datum point

0 500 ft
0 100 m

Figure 142. Computer-generated map of the top of the Herrin (No. 6) Coal in study area 5 of mine B. Interference pattern of two structure trends are visible; general trend in this overall area is north-south, and local trend is east-west. The locations of anomalies in the structure contours appear to be related to the location of the shear body and of other deformational features. Contour interval: one foot; grid size: 100 feet.

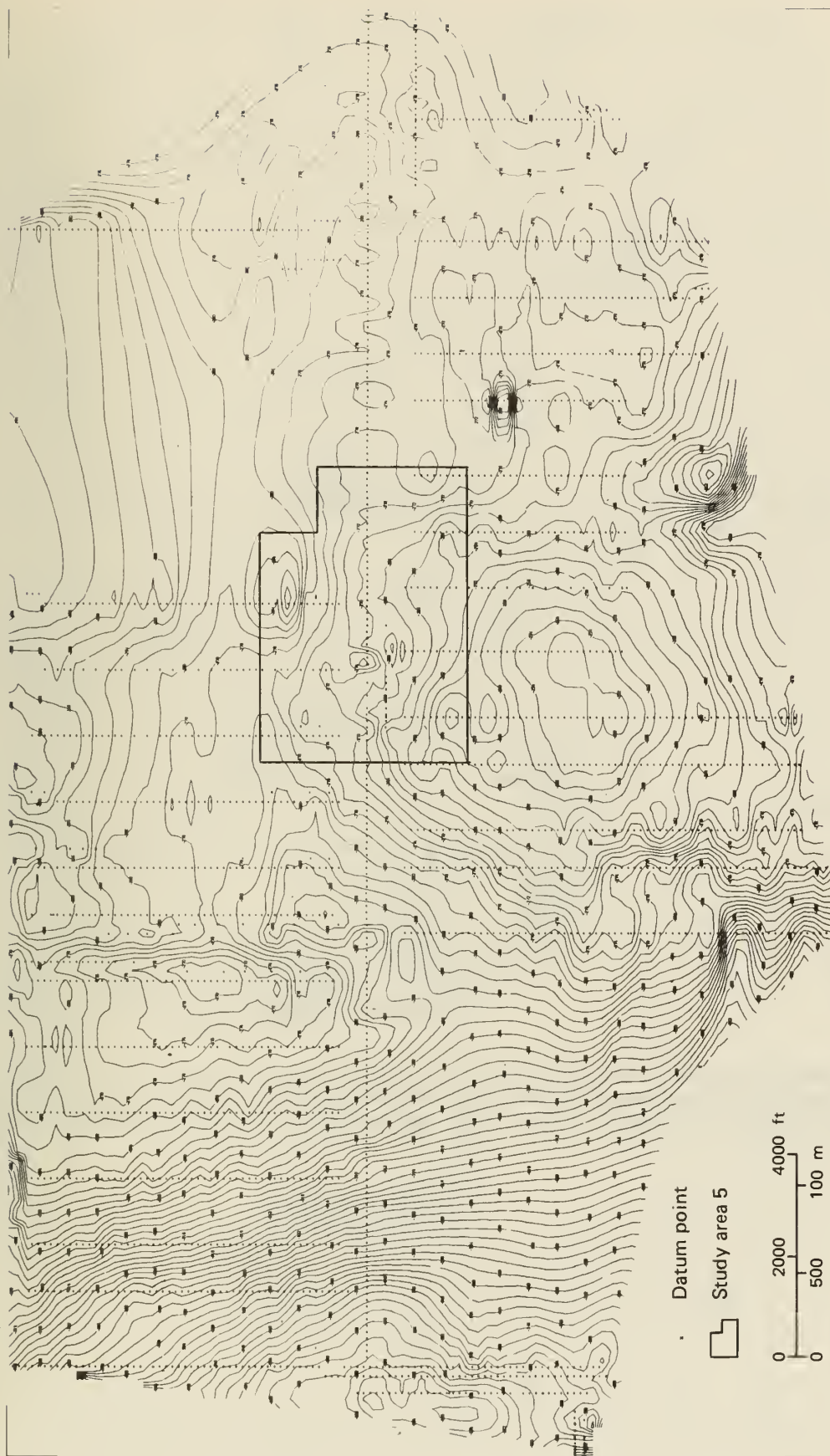


Figure 143. Computer-generated map of the top of the Herrin (No. 6) coal in the area of study area 5 of mine B. The general north-south trend of the region is dominated by a local east-west trend of structure lines, which produced small irregularities and interference patterns. Contour interval: two feet; grid size: 100 feet.

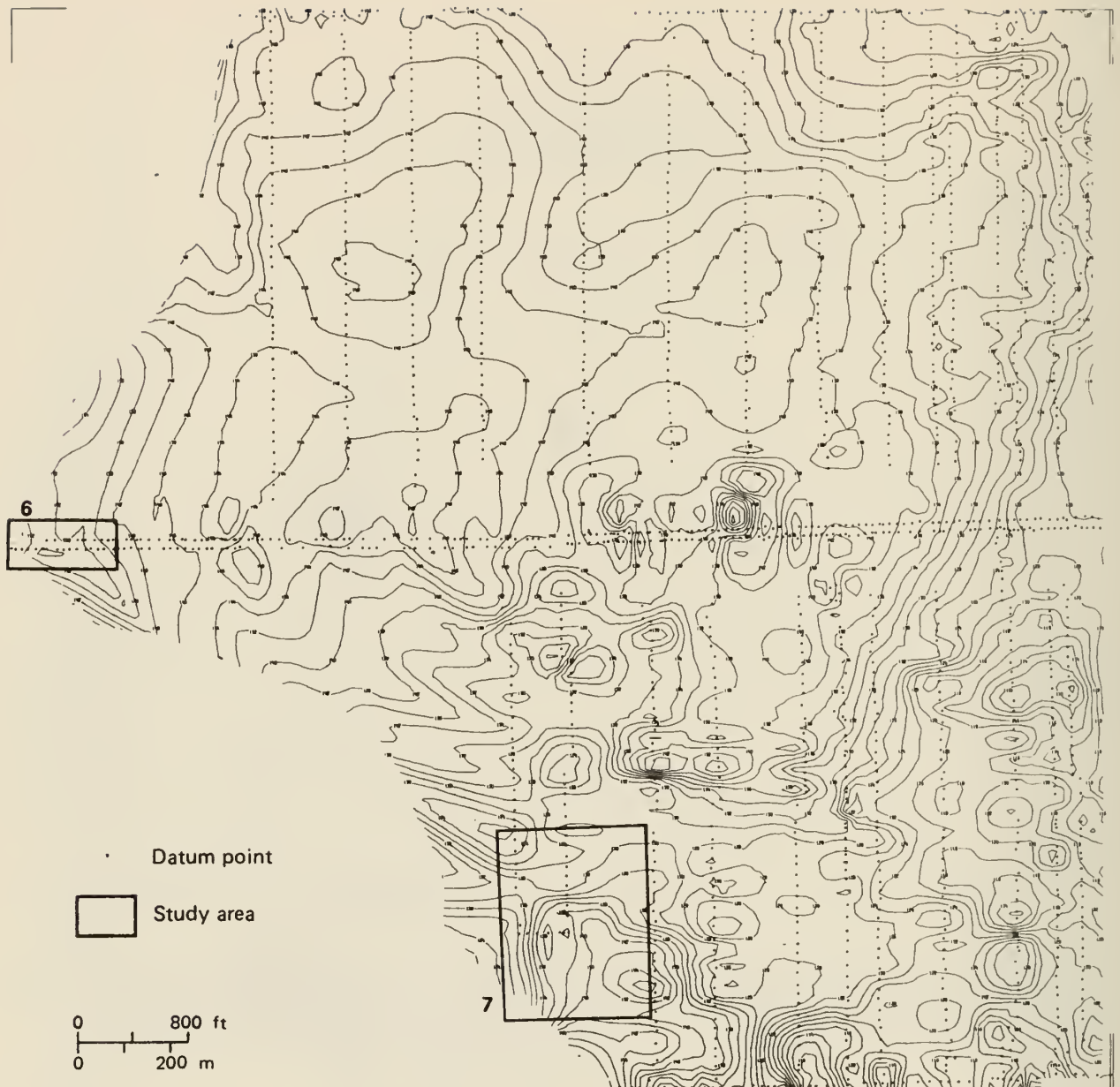


Figure 144. Computer-generated map of the top of the Herrin (No. 6) Coal at mine C, study areas 6 and 7. For the more regional setting, see figure 149. Structural anomalies of the top of the coal reflect anomalies in the roof strata composed mainly of laminated siltstone and sandstone, which locally impose severe problems for roof control. Contour interval: two feet; grid size: 100 feet.

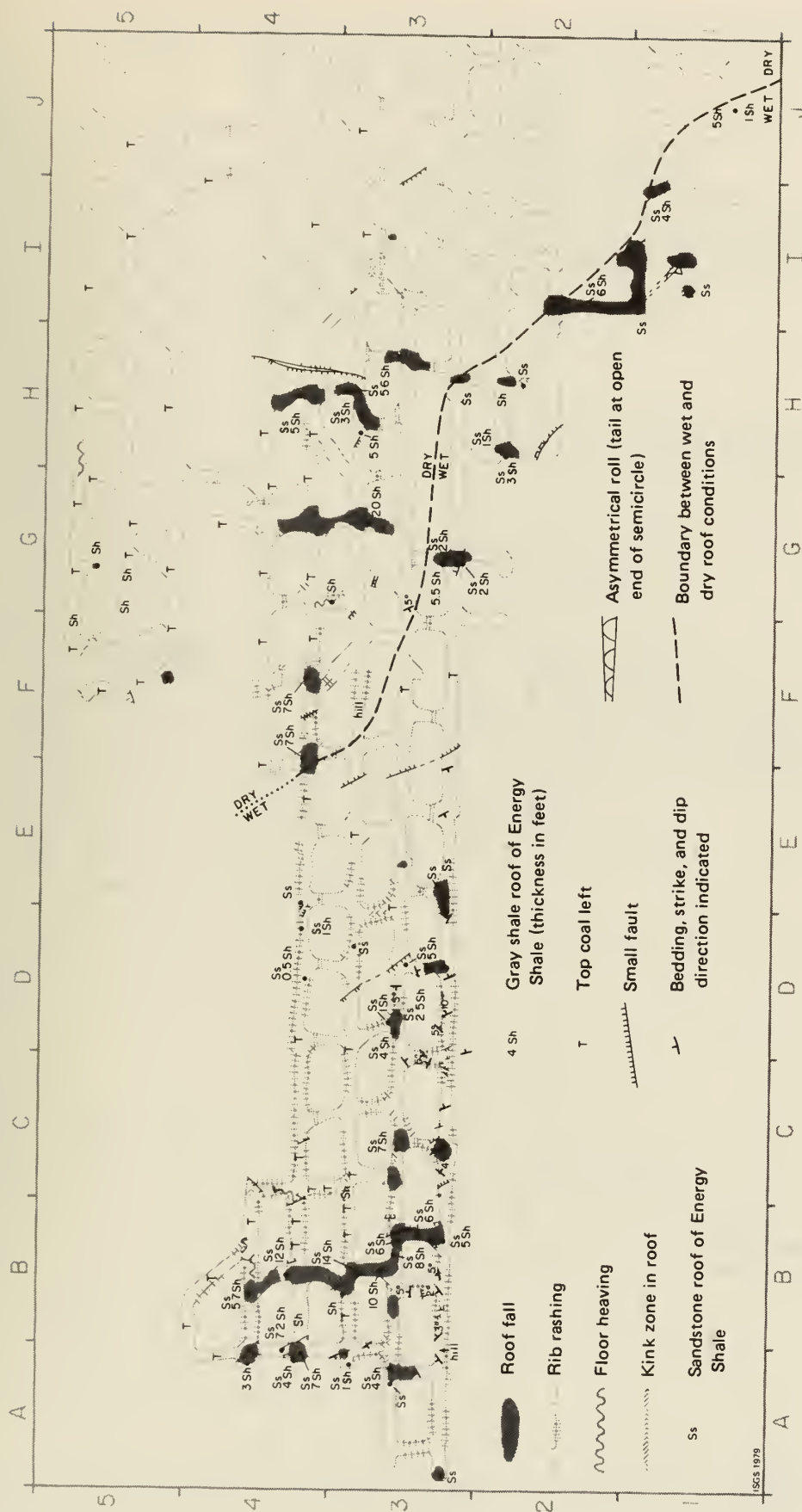


Figure 145. Lithology and minor fault structures of the Herrin (No. 6) Coal and its immediate roof strata, and distribution of roof falls and other induced instabilities in study area 6 of mine C.



Figure 146. Occurrence and development of roof falls in study area 6 of mine C as mapped during three different periods. Although excavation did not continue, the roof continued to fall for more than half a year.

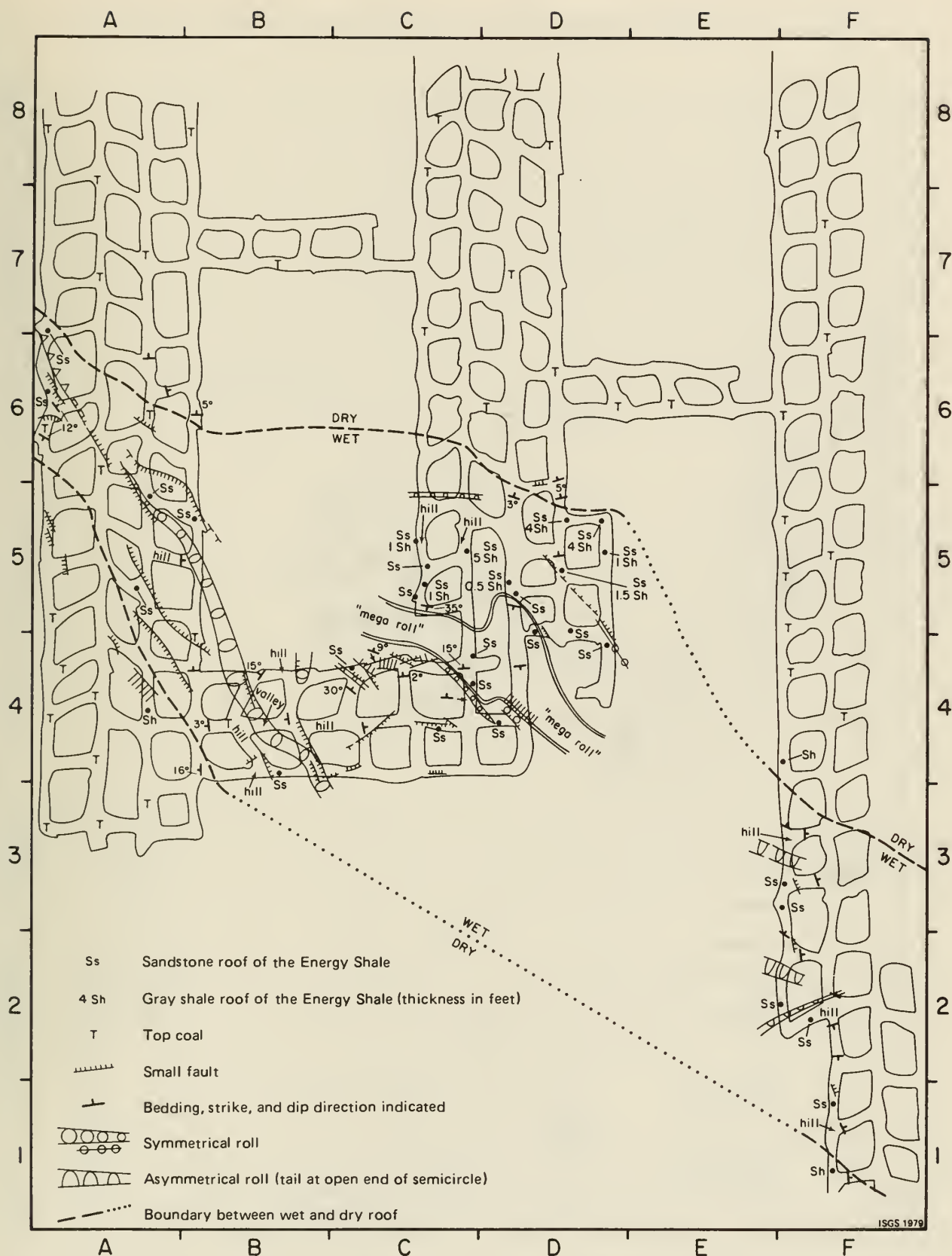


Figure 147. Lithology, rolls, and fault structures of the Herrin (No. 6) Coal and its immediate roof strata in study area 7, mine C.

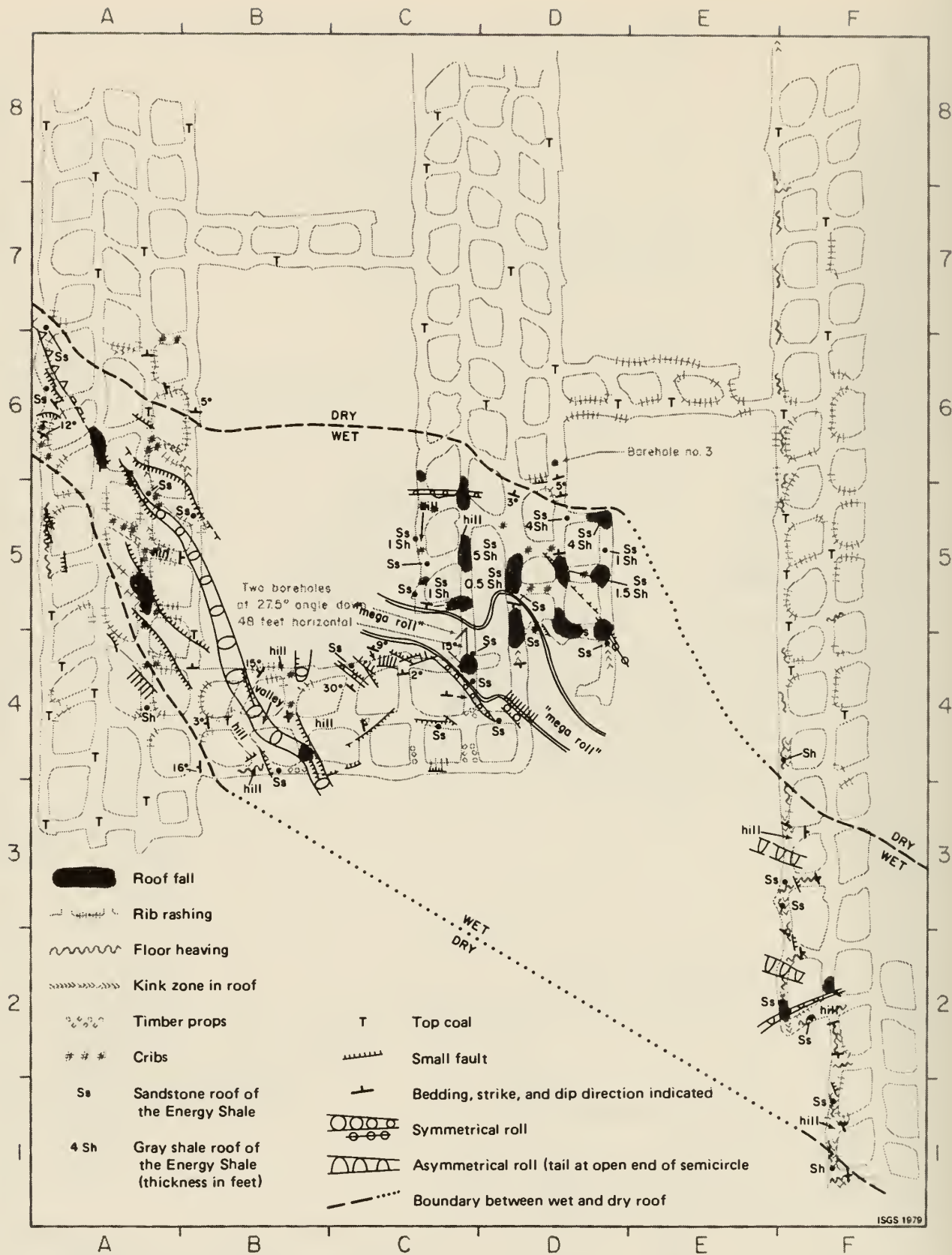


Figure 148. Lithology, rolls, and fault structures of the Herrin (No. 6) Coal and its immediate roof strata, and the distribution of roof falls and other induced instabilities and additional roof support in the area below siltstone and sandstone with water seepage. Study area 7, mine C.

Results from computer-generated maps of thickness and structure

The computer-generated maps presented here and in the previous chapter (figs. 83-85) differ considerably from those of in-mine mapping. They differ not only in scale and content, but particularly in number and density of data points. They are less biased than hand-drawn maps, but they lack any geological judgment in their display. Since the frequency of data points is low in comparison to the variability of thicknesses and structural contours known from in-mine mapping, all computer-generated maps must be interpreted with caution, especially if statements are made for areas as small as a single mine. The maps are best suited for studying and interpreting broad regional trends. Details of the computer-generated maps in this report are given in table 2. The maps represent generalized thicknesses and structures. The density of data points averages one data point per section. The features on the maps cannot serve as accurate indicators of the distribution of thickness. The maps are useful as guides to thickness trends and statistical variability of the rock units in different areas of the state, however.

TABLE 2. Details of mapping for computer-generated maps of thickness and structure.

Figure number	Size of area mi ² (km ²)	Ave. distance between points mi (km)	Grid size ft (m)	Max. search distance ft (m)	Total No. of data points	Approx. no. of data points outside map
149, 150, 151, 152	540 (1,398)	1.2 (1.93)	5,000 (1,525)	50,000 (15,240)	574	200
153, 154, 155, 156	1,620 (3,226)	1.6 (2.58)	5,000	50,000	817	250
83, 84, 85, 157	6,400 (16,576)	1.5 (2.4)	5,000	50,000	4,500	1,000

Maps of the thickness trends of the Anna Shale, Brereton Limestone, and Conant Limestone Members in southwestern and southern Illinois are included in the previous chapter (figs. 83-85). Since the more detailed studies for this report were done in the "Quality Circle" area and in west-central Illinois, computer-generated maps of these two areas were produced on a larger scale.

Figures 149 and 153 show the general structural trend of the coal seam within the regional setting. In west-central Illinois and the "Quality Circle" area, the overall coal-structure trend is almost north-south. The coal bed dips gently to the east toward the interior of the Illinois Basin Coal Field. The Walshville channel and the Rend Lake Fault System were mapped during previous studies and overlain on the maps. They are not reflected as well in the structural contour map as in the thickness maps.

A variation in trend supersedes the coal locally or along some narrow zones. The east-west-striking Cottage Grove Fault System (figs. 3 and 59), located south of the area in figure 149, is reflected on the map as an east-west trend of structural contours and an alignment of shallow troughs in T5S. The Du Quoin Monocline strikes north-south over a long distance, bifurcates in the area of T3S-R1W, R1E, and branches off towards the northeast. Structural contour lines follow the same trend, whereas the Walshville channel does not appear to have been influenced by the development of the northeast-trending branch of the monocline.

No correlation of the contour lines of coal structure and the distribution of the thick Energy Shale is recognizable.

The thickness maps demonstrate the following interrelationships of the roof rocks:

1. The regional association of the Energy Shale with the Walshville channel in the "Quality Circle" area is shown in figure 150. It can also be inferred from the absence of Anna Shale and Brereton Limestone (figs. 83 and 84) and from the thick interval between top of the coal and bottom of the first overlying limestone thicker than two feet for the "Quality Circle" area in Jefferson and Franklin County, for the "Troy area" in Clinton and St. Clair Counties, and for the "Hornsby area" in Montgomery and Macoupin Counties.
2. Where thick (>20 feet) Energy Shale or the Walshville channel fill accumulated, a decreasing thickness or absence of Anna Shale and of Brereton Limestone was found (compare figs. 150 and 151 and 152; also see figs. 154 and 155).
3. Both Anna Shale and Brereton Limestone vary in thickness and occur in lenticular patches or elongate troughs. Their interrelationship is an important factor in roof stability.
4. Throughout the mapping area an inverse relationship between the thickness of Anna Shale and Brereton Limestone can be recognized. Where the Anna Shale is thin or absent, commonly a thick Brereton Limestone is found. Where the Anna Shale is thick the Brereton Limestone appears to be thin or absent (compare fig. 151 with 152 and fig. 154 with 155, see table 13, p. 193). This reciprocal relationship also has been recognized during in-mine mapping, especially in study areas 1 to 3 (figs. 119, 126, and 134) of mine A.
5. The Brereton Limestone—normally in patches or troughs ranging in thickness from 0 to 6 feet (1.8 m) or even as much as 8 feet—was accumulated in even greater thickness close to the Walshville channel, with extremes as thick as 20 feet. (Compare figs. 84, 152, and 155.)

Experience in mines with black shale-limestone roof throughout Illinois indicates that thickness of the interval from the top of the coal to the base of the first limestone bed thicker than two feet is a significant factor for roof stability. A thick limestone bed strengthens the roof, especially if it is close to the top of the coal, where it provides a strong anchor for roof bolts. This study recognized that a minimum thickness of two feet of limestone is needed to reduce the likelihood of roof falls. Less than two feet of limestone in the immediate roof increases the hazards, especially where the Anna Shale also is thin or absent.

The interval from the top of the Herrin (No. 6) Coal to the base of the first thick limestone bed ranges from 0 to more than 100 feet (30 m) (figs. 156 and 157). Usually, however, the interval is less than 12 feet thick. Within the Walshville channel and areas having thick gray shale wedges, the interval increases in thickness to 100 feet and more. Where the interval exceeds thicknesses of 6 feet, the Brereton Limestone may be considered thin or absent. Where it exceeds 15 feet, the individual benches of the Bankston Fork Limestone are probably less than two feet thick or missing. In the Walshville channel and areas of thick gray shale, the Brereton and the Bankston Fork are commonly thin or absent where the interval exceeds 20 feet. In this case the first limestone thicker than two feet is probably the Piasa Limestone Member of the Modesto Formation.

In areas where the Energy Shale is thick and the interval to the first limestone is more than 20 feet, the lack of a competent limestone alone does not usually cause roof problems. Roof conditions in these areas are probably similar to those known from most mines in the "Quality Circle." Spots are scattered throughout the maps (figs. 156 and 157), especially in Bond, Fayette, and Montgomery Counties, where the interval to the first limestone exceeds 20 feet. These small areas cannot be connected with known channels. Their stratigraphic succession is probably similar to that observed in mine A, where the Brereton Limestone is discontinuous and the Bankston Fork Limestone thins in places to almost zero. The entire succession, however, is that of a black shale-limestone roof without a competent limestone. Hazardous roof instabilities result from this situation, which, if recognized early enough, can be controlled by means of roof support.

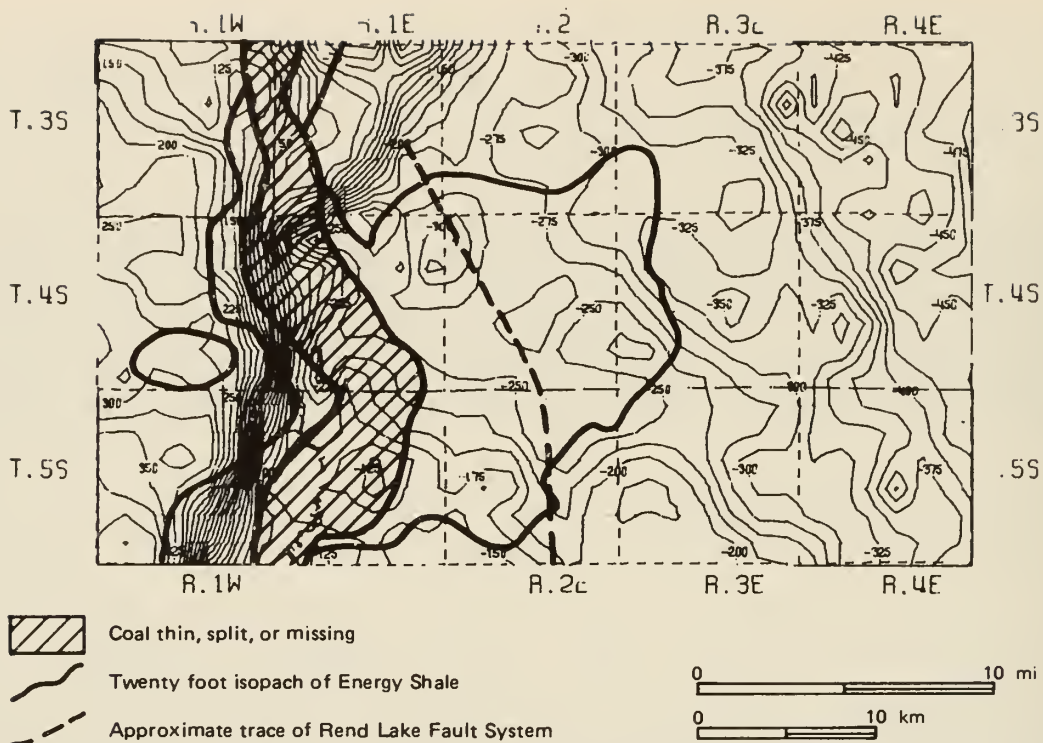


Figure 149. Map of the top of the Herrin (No. 6) Coal Member in the "Quality Circle" area. Contour interval: 25 feet. Greater data-point density was used to outline areas of thin, split, or missing coal and the approximate location of the Rend Lake Fault System.

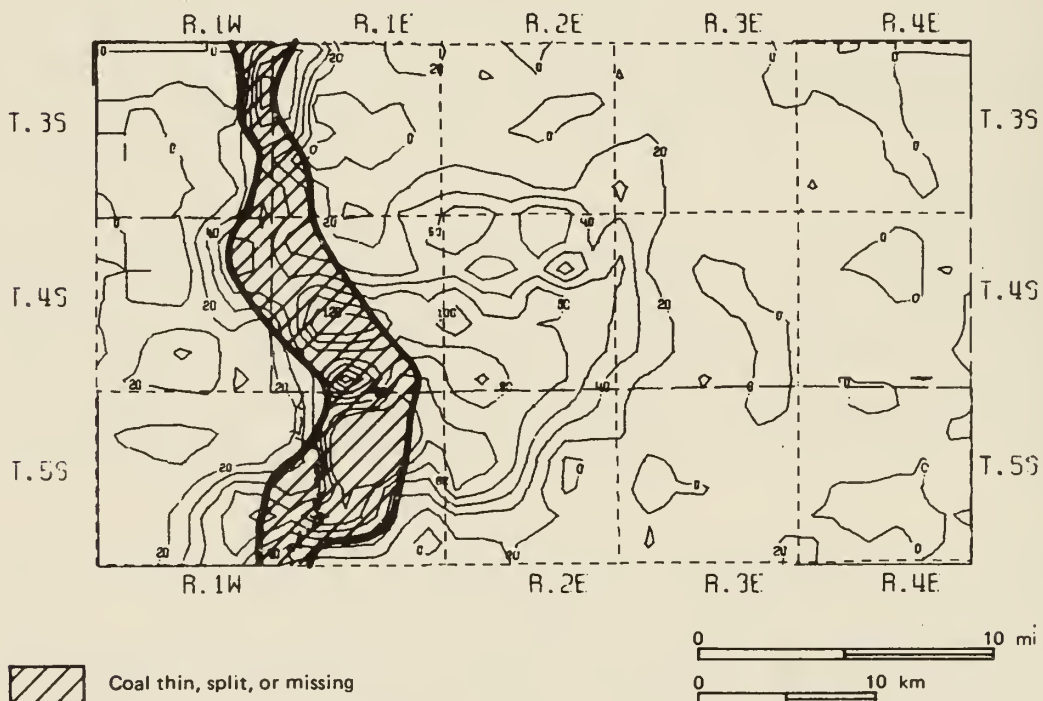


Figure 150. Thickness trends of the Energy Shale Member in the "Quality Circle" area. Contour interval: 20 feet; highest contour allowed: 140 feet. The Energy Shale is thickest in the Walshville channel area and rapidly decreases in thickness westwards; however, thin lenticular bodies of Energy Shale have been found as far west as Randolph County. Energy Shale, 20 feet or thicker extends eastward from the channel in form of a large lobe. It rapidly decreases in thickness farther toward the east. Greater data-point density was used to outline areas of thin, split, or missing coal and the approximate location of the Rend Lake Fault System.

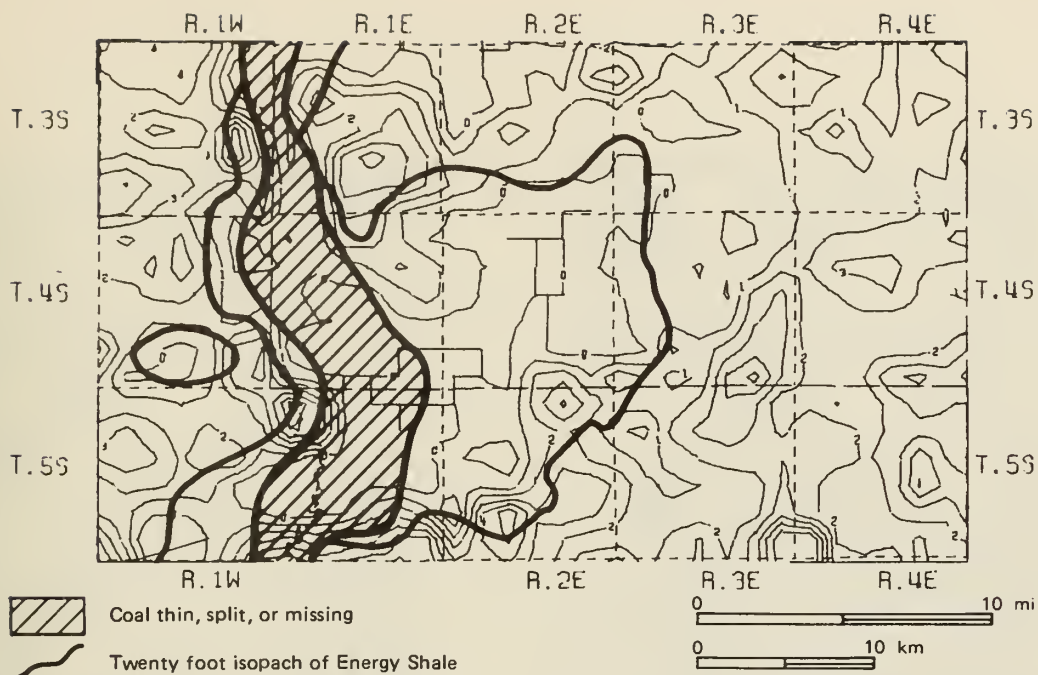


Figure 151. Thickness trends of the Anna Shale Member in the "Quality Circle" area. Contour interval: 1 foot; highest contour allowed: six feet. The map shows the patchy and lenticular occurrence of the Anna Shale, just as found in Bond and Montgomery Counties in west-central Illinois. Anna Shale is thin or entirely missing in areas where the Energy Shale is thick. Greater data-point density was used to outline areas of thin, split, or missing coal and the approximate location of the Rend Lake Fault System.

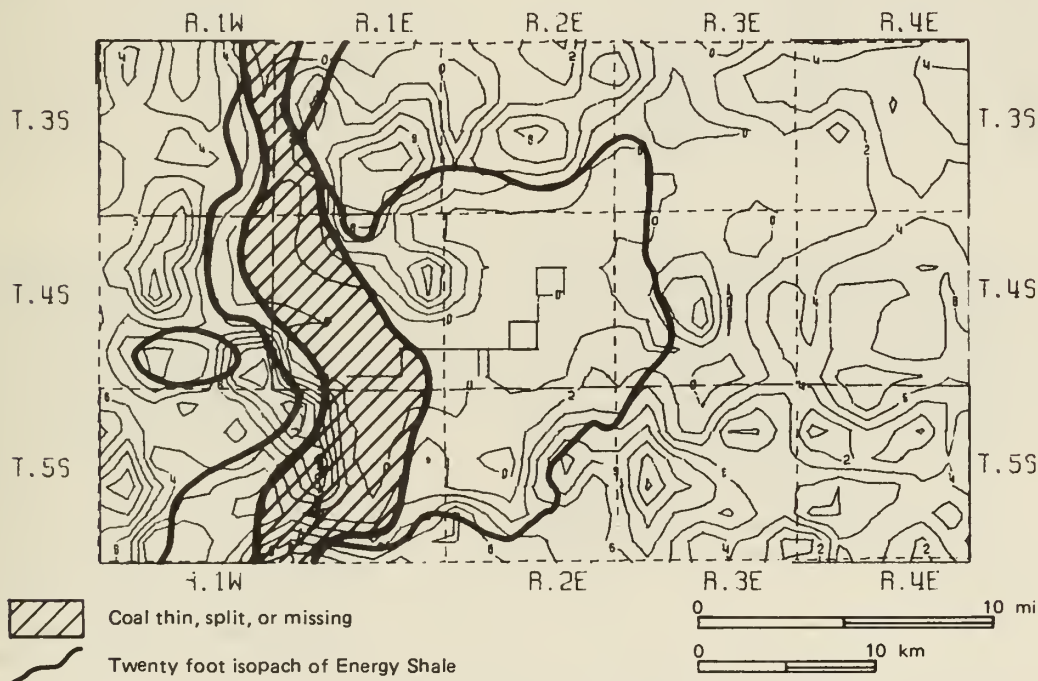


Figure 152. Thickness trends of the Brereton Limestone Member in the "Quality Circle" area. Contour interval: 2 feet; highest contour allowed: 14 feet. The map of the Brereton Limestone at first appears similar to figure 151. The pattern and distribution of thickness seem to be comparable to those in Bond and Montgomery Counties. The Brereton is thin or absent in areas of thick Energy Shale, whereas it is very thick to the west of the Walshville channel. In some locations it is also thin or absent where the Anna Shale is thick (especially visible at the border between R3E and R4E in T5S). The same reciprocal relationship can be found in the eastern sector of R2E and T3S and in the center of R3E and T4S. Greater data-point density was used to outline areas of thin, split, or missing coal and the approximate location of the Rend Lake Fault System.

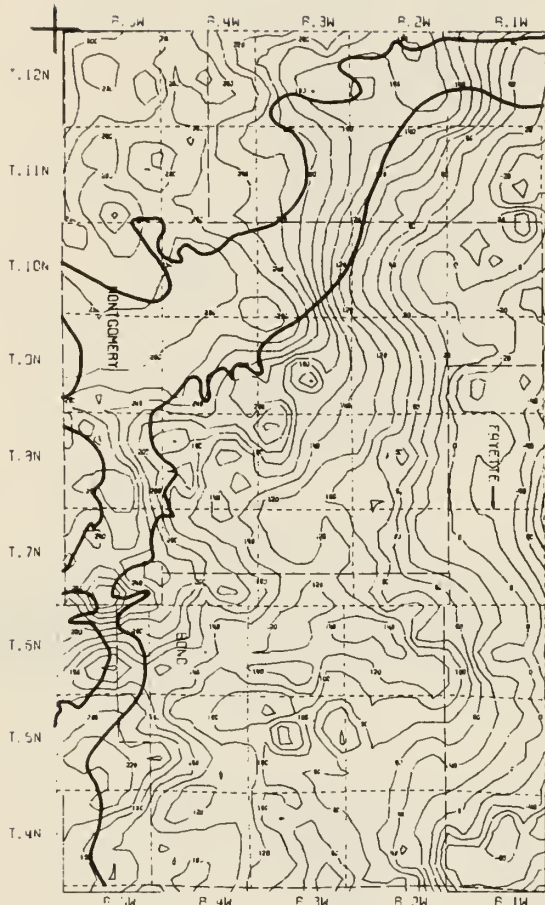


Figure 153. Map of the top of the Herrin (No. 6) Coal Member in Bond and Montgomery Counties. Contour interval: 20 feet. The general trend of the coal contours is NNE-SSW. The coal dips gently from elevations of greater than 300 feet in the northwestern corner of the map to elevations below less than 80 feet in the eastern and southeastern part of the map. Major anomalies are displayed in the zone where the Walshville channel crosses the coal seam. Study areas 1 to 3 are located in this map area. Areas having ≥ 2 miles between data points: 7N-1W, 6N-1W, 5N-1W, 4N-1W, 11N-4W, 11N-3W, 10N-5W. Greater data-point density was used to outline areas having thin, split, or missing coal.

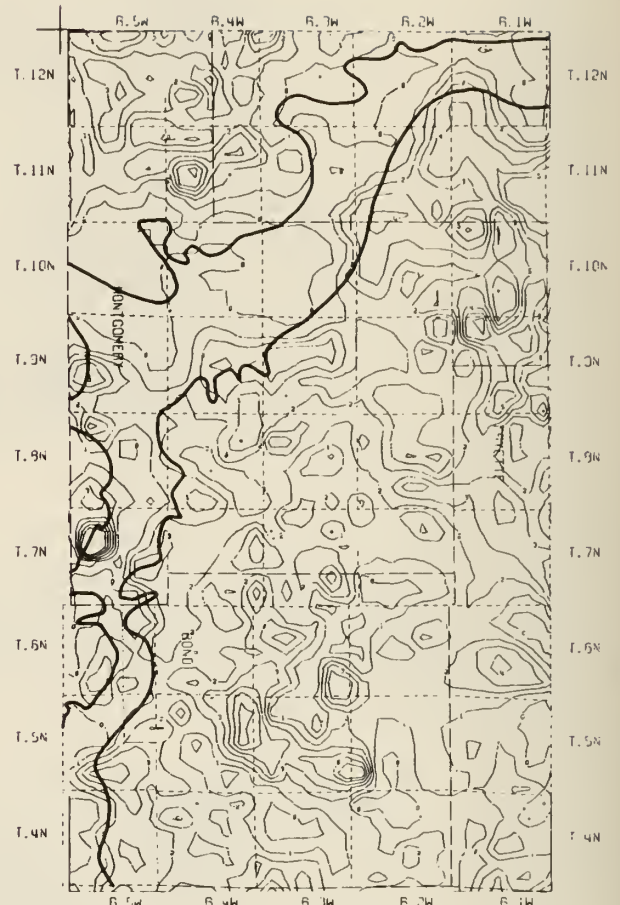


Figure 154. Thickness trends of the Anna Shale Member in Bond and Montgomery Counties. Contour interval: one foot; highest contour selected: six feet. The isopach map shows the patchy and very lenticular occurrence of the Anna Shale just as it was observed for the "Quality Circle" area and for the rest of southern and southwestern Illinois (figs. 151 and 83). The Anna Shale is generally less than four feet (< 1.2 m) thick but may locally exceed six feet (1.8 m) in thickness. Neither a regular distribution pattern nor a trend in Anna Shale thickness is visible. The lenticular pattern, however, has been observed in study areas 1, 2, and 3. Areas having ≥ 2 miles between data points: 7N-1W, 6N-1W, 5N-1W, 4N-1W, 11N-4W, 11N-3W, 10N-5W. Greater data-point density was used to outline areas having thin, split, or missing coal.

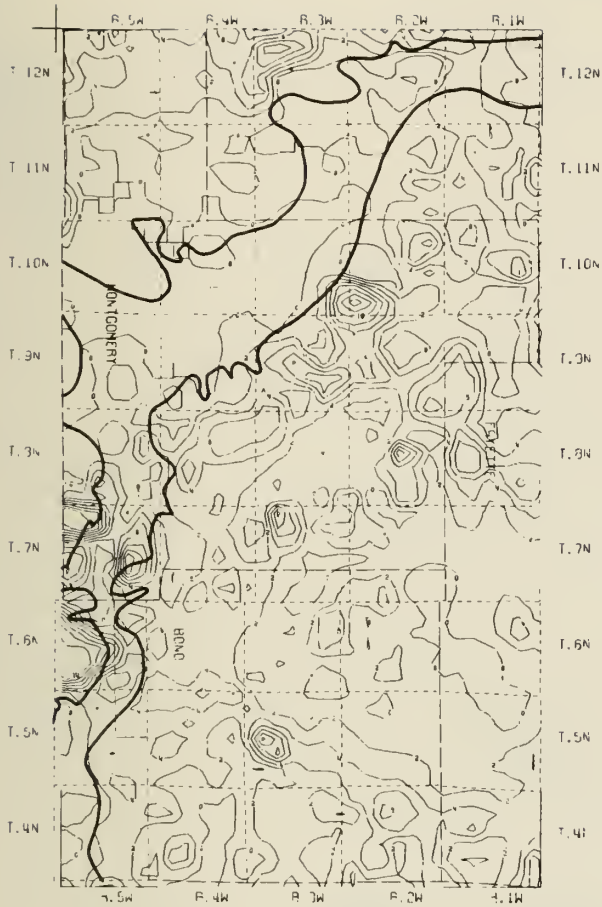


Figure 155. Thickness trends of the Brereton Limestone Member in Bond and Montgomery Counties. Contour interval: two feet; highest contour selected: 14 feet. Areas having ≥ 2 miles between data points: 7N-1W, 6N-1W, 5N-1W, 4N-1W, 11N-4W, 11N-3W, 10N-5W. Greater data-point density was used to outline areas having thin, split, or missing coal.

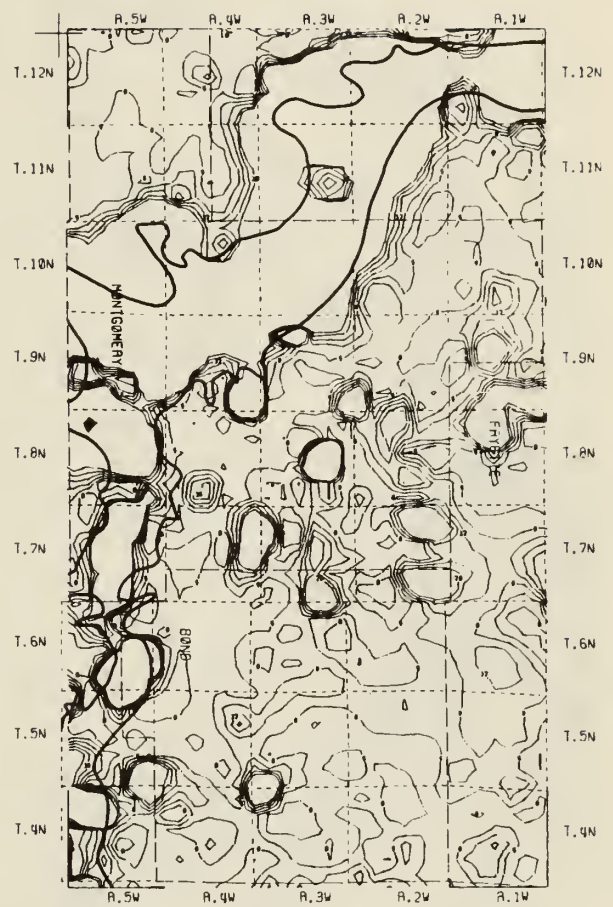


Figure 156. Thickness trends of the interval from the Herrin (No. 6) Coal Member to the first thick limestone bed (> 2 feet) in Bond and Montgomery Counties. Contour interval: three feet; highest contour allowed: 15 feet. Areas having ≥ 2 miles between data points: 7N-1W, 6N-1W, 5N-1W, 4N-1W, 11N-4W, 11N-3W, 10N-5W. Greater data-point density was used to outline areas of thin, split, or missing coal.

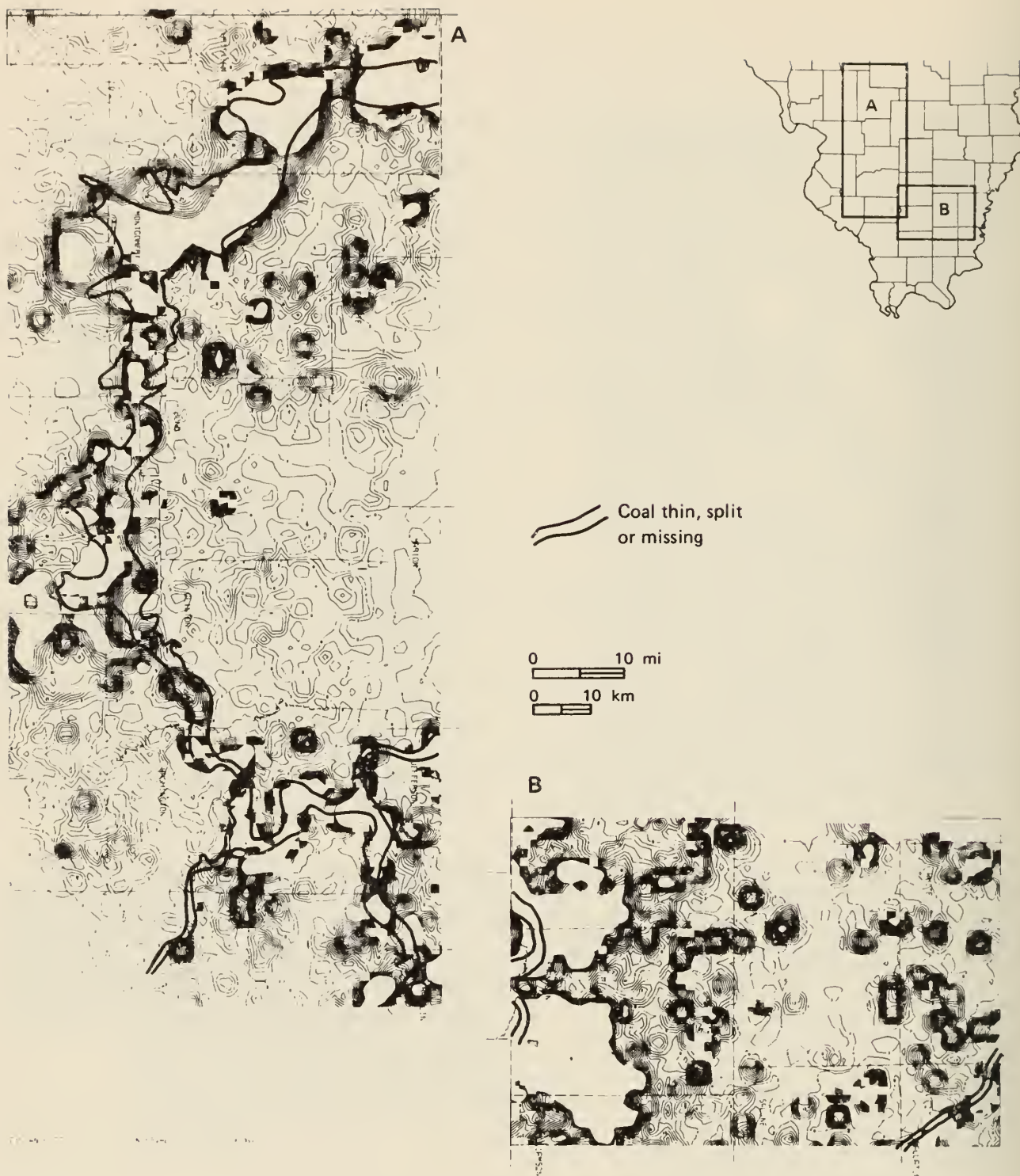


Figure 157. Thickness trends of the interval from the Herrin (No. 6) Coal Member to the first thick limestone bed (> 2 feet; 60 cm) in southwestern and southern Illinois. Contour interval: 4 feet; highest contour allowed: 20 feet. Greater data point density was used to determine the location of the Walshville channel.

OBSERVATIONS AND DISCUSSION OF ROOF FAILURE TRENDS

General observations

The geologic setting and cause of roof falls is often evident. The following generalizations can be made about roof conditions as designated in this report:

1. Gray shale roof (overlying 10 percent of identified coal resources):
 - A. The occurrence of rolls, minor faults and shears is almost ubiquitous. Although roof stability is generally good, locally the roof may be difficult to control (fig. 158).
 - B. The laminated sandstone/siltstone facies is prone to separation along bedding-surfaces. Roof bolts of uniform length with mechanical anchors appear to enhance this tendency (fig. 159).
 - C. The gray shales are characteristically low in slake durability, resulting in local spalling of the roof. Where water is encountered in the roof, such as near channel sandstones, massive arched roof failures are abundant (fig. 160).
2. Black shale-limestone (overlying 90 percent of identified coal resources):
 - A. Where a thick limestone (>0.6 m) forms the immediate roof, roof problems are rare, regardless of the presence of faults, joints, and clay dikes (fig. 161).
 - B. Where the fissile black shale occurs as the immediate roof, the number of roof falls is in proportion to the number of structural anomalies (faults or concretions) in the roof. These falls seldom break upward past the first massive limestone layer thicker than 0.6 m (fig. 162).

The lithologic distribution of the immediate roof and the frequency of occurrence of structural anomalies in the roof have been calculated from the maps for the eight study areas. The intersections of entries and crosscuts were used as the sampling points for each of the areas, since they are rather evenly distributed and generally are the locations of the serious roof falls. Table 3 shows the percentage of the intersections in the given study area with specific lithology of the immediate roof. Table 4 shows the percentage of intersections in the given study area with specific structural features in the immediate roof.

Although the study areas are representative of conditions in the Herrin (No. 6) Coal roof, these calculated distribution coefficients are of undetermined statistical value for the entire Illinois Basin Coal Field, because the total area mapped represents only a

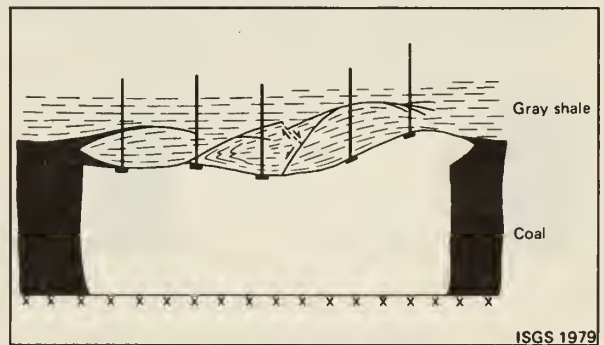


Figure 158. Rolls in roof. Rolls are common in the gray shale and cause unevenness of the roof. Fractures or faults in the rock cause many rolls to fall before bolting; others fall later despite roof bolts. Large rolls may protrude into and replace part of the upper coal.

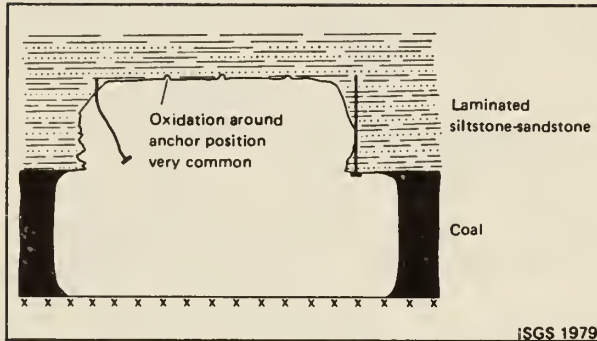


Figure 159. Laminated siltstone-sandstones. Mechanical anchors may initiate separation of the roof along the bedding plane. In normal roof widths of 16 to 20 feet (4.8 to 6 m), the rock strength usually is adequate to maintain the separated rock slab. At intersections, the span of 20 to 35 feet is too great for self support. The horizontal compressive stresses within a foot of the rib are greater than the rock strength. The roof will separate bed by bed until the roof falls.

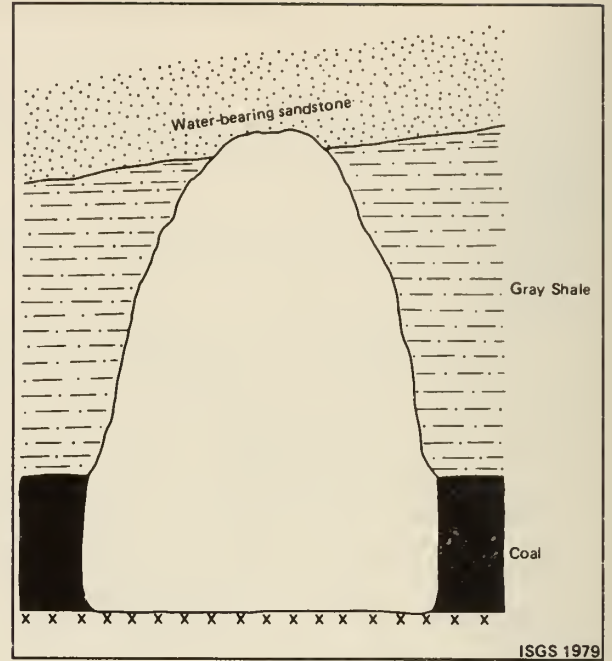


Figure 160. Wet zones in Energy Shale. Where seepage in the roof is locally encountered, large arched falls are common. The low shale durability in wet conditions can decrease roof support by bolts considerably. Both mechanical anchors and resin bolts have locally proved ineffective in areas of abundant seepage. Bolts fall with the rock.

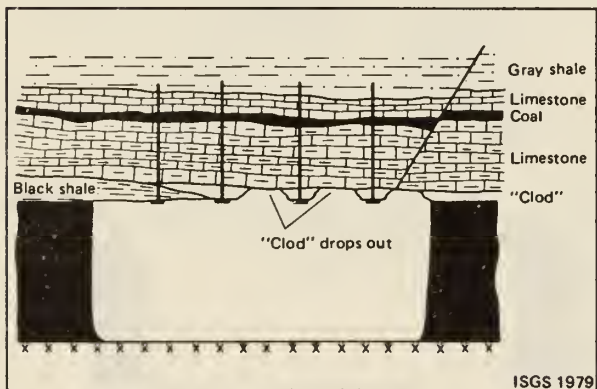


Figure 161. Limestone roof. Best roof conditions are found where the Brereton Limestone is greater than 1.5 to 2.0 feet (0.4 to 0.6 m) in thickness. Bolts are probably not supporting the roof but are merely inhibiting slabbing of the "clod." The crumbling and slaking quality of the "clod" in a number of mines led to unnecessary cribbing.

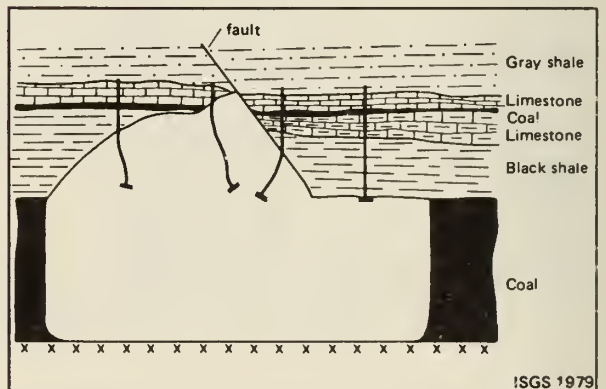


Figure 162. Black shale or "draw slate." Numerous falls occur, and their number is proportional to the number of faults, and slicksided surfaces. Where the Brereton is thin or absent, roof strata up to the next thick limestone will usually fall. If falls do not stop at the second (Conant) limestone, the Lawson Shale up to the Bankston Fork Limestone (6 to 10 feet above the coal) will usually fall.

TABLE 3. Percentage of intersections of entries and crosscuts with different lithologies in the immediate roof of the Herrin (No. 6) Coal.

Roof type	Study area	Intersections, sample size (100%)	Lithology of immediate roof of the Herrin (No. 6) Coal			
			Black shale (Anna Sh.) (%)	Limestone over black shale (Brereton Ls. over Anna Sh.) (%)	Limestone (Brereton Ls.) (%)	Other (Jamestown to Lawson) (%)
Black shale-limestone roof	1	249	44	44	12	0
	2	472	51	16	29	4
	3	215	61	not designated	37	2
			Dark-gray shale (%)	Medium-gray shale (%)	Siltstone/Sandstone	
					wet (%)	dry (%)
Gray shale roof	4	311	75	25	0	0
away from channel	5	291	49	51	0	0
Gray shale roof near channel	6	153	0	0	44	56
	7	184	0	0	42	58
	8	158	0	32	68	0

TABLE 4. Percentage of intersections of entries and crosscuts with different structural features in the immediate roof of the Herrin (No. 6) Coal.

Roof type	Study area	Intersections, sample size (100%)	Faults (%)	Slips (%)	Free (%)
Black shale-limestone roof	1	249	34	26	41
	2	472	19	35	46
	3	215	7	31	62
			Rolls (%)	Shears and slips (%)	Free (%)
Gray shale roof	4	311	7	8	85
	5 total	291	12	32	56
	outside shear body	(189)	(18)	(9)	(73)
	inside shear body	(102)		(74)	(26)
	6	153	5	2	93
	7	184	12	7	81
	8	158	4	3	93

few square miles of the approximately 10,000 square miles of Herrin (No. 6) Coal that is greater than 42 inches (1 m) thick.

Frequency and distribution of roof falls

The classification and cataloging of roof falls were not part of this roof study, nor would they be feasible unless a comprehensive evaluation of the occurrence of roof falls with respect to the entire history of excavation and support and subsequent annual investigations were undertaken. The majority of the areas mapped had been mined some time ago, generally months (years, in some cases) before they were mapped. For this reason, the conclusions reached here partially reflect the long-term stability of mine excavation. Study areas 2, 6, 7, and 8 were, in part, active headings during mapping.

Table 5 is a tabulation of the number of roof falls mapped in each of the study areas, as well as the percentage of fallen intersections and rooms. It should be noted that the number of fallen intersections is greater than the number of fallen rooms. Probably 70 or 80 percent of the large falls occur at intersections. This undoubtedly depends on the spans of the intersections, which are usually 50 percent and sometimes 100 percent greater than the spans in rooms.

FALL DISTRIBUTION RELATED TO THE TYPE OF LITHOLOGY IN THE IMMEDIATE ROOF

For each of the study areas, the number of fallen intersections has been tabulated as a function of lithology of the immediate roof (table 6). As indicated earlier, the roof falls in areas having the black shale-limestone type of roof (study areas 1, 2, and 3) dominated where the Brereton Limestone is

TABLE 5. Relation of stable and fallen interaactiona
and of roof falla in rooma and interaactiona.

Study area	Sample size (number of intersections)	Number of stable intersections	Number of fallen intersections	Percentage of fallen intersections	Number of mapped roof falla				
					Falls (total)	Number of fallen intersections (I)	Number of fallen rooms (R)	I/R	Room (%)
1	249	198	51	20	80	51	29	1.8	64
2	472	411	61	13	98	61	37	1.6	62
3	215	189	26	12	54	26	29	0.9	48
4	311	296	10	3	12	10	2	5.0	83
5 total	291	236	55	19	75	55	20	2.8	73
outside shear body	(189)	(181)	(8)	(4)	(13)	(8)	(5)	(1.6)	(62)
inside shear body	(102)	(55)	(47)	(46)	(62)	(47)	(15)	(3.1)	(76)
6	153	119	34	22	39	34	5	6.8	87
7	184	172	12	7	18	12	6	2.0	67
8	158	126	32	20	40	32	8	4.0	80

TABLE 6. Occurrence of fallen intersections
for different lithologies of immediate roof.

Roof type	Study area	Total number of intersections	Black shale (Anna Shale)			Limestone (Brereton Ls.) over Black Shale (Anna Sh.)			Limestone (Brereton Ls.)			Other		
			No. of falls	Size of sample	Percent fallen	No. of falls	Size of sample	Percent fallen	No. of falls	Size of sample	Percent fallen	No. of falls	Size of sample	Percent fallen
Black shale- limestone roof	1	249	36	109	33	18	110	16	0	30	0	—		
	2	472	46	242	19	11	74	15	0	135	0	4	21	19
	3	215	25	132	19	—			1	79	1	0	4	0
			Gray shale			Dark-gray shale			Siltstone/Sandstone					
			No. of falls	Size of sample	Percent fallen	No. of falls	Size of sample	Percent fallen	Wet			Dry		
Gray shale roof	4	311	1	77	1	9	234	4	—			—		
	5 total	291	18	149	12	37	142	26	—			—		
	outside shear body	(189)	0	(112)	0	8	(77)	10	—			—		
	inside shear body	(102)	18	(37)	49	29	(65)	45	—			—		
	6	153	—			—			26	67	39	8	86	9
	7	184	—			—			12	77	16	0	107	0
	8	158	3	50	6	—			29	108	27	—		

thin or absent. As indicated by table 6, the percentage of fallen intersections for such an area ranges from 15 to 33 percent and is limited to non-limestone roof. The areas of gray shale roof do not exhibit such distinct lithologic changes, and, as a result, the fall coefficient is not as well defined; however, it appears that the laminated sandstone/siltstone is more prone to fall than the almost uniform gray or dark-gray shale, especially if the sandstone/siltstone is water bearing.

FALL DISTRIBUTION RELATED TO THE OCCURRENCE OF STRUCTURAL FEATURES

The number of fallen intersections has been tabulated as a function of structural anomaly (table 7). Only structural features that were of major importance were used for this tabulation. For the black shale-limestone areas, the term "fault" includes clay dikes, clay-dike faults, and faults that displace the top of the coal. The term "slip" includes small faults that produce little or no displacement of the coal and slickensided surfaces. The term "free" indicates a lack of slips or faults but a possible occurrence of concretions or joints.

For areas of gray-shale roof, the term "roll" includes all sizes of rolls. The terms "shear and slip" refer to all faults, displacements, and slickensided surfaces not associated with the occurrence of a roll. The term "free" indicates a lack of rolls or shears and slips but a possible occurrence of joints or concretions.

The most critical factor in regard to roof stability is the presence of faults, shears, or slips in the rocks rather than the magnitude of displacement or size of a roll; however, as with the lithologic distribution, the statistical validity of these coefficients for the entire Illinois Basin Coal field cannot as yet be evaluated.

TABLE 7. Occurrence of fallen intersections
for different structures in the immediate roof.

Roof type	Study area	Total number of intersections	Faults			Slips			Free		
			No. of falls	Size of sample	Percent fallen	No. of falls	Size of sample	Percent fallen	No. of falls	Size of sample	Percent fallen
Black shale-limestone roof	1	249	20	84	24	18	64	28	13	101	13
	2	472	17	90	19	28	167	17	15	215	7
	3	215	4	14	29	15	67	22	7	134	5
			Rolls			Shears and slips			Free		
			No. of falls	Size of sample	Percent fallen	No. of falls	Size of sample	Percent fallen	No. of falls	Size of sample	Percent fallen
Gray shale roof	4	311	0	23	0	0	25	0	10	263	4
	5 total	291	0	34	0	51	92	55	4	165	2
	outside shear body	(189)	0	(34)	0	4	(17)	24	4	(138)	3
	inside shear body	(102)	—	—	—	47	(75)	63	0	(27)	0
	6 wet	153	2	7	29	1	1	100	23	59	39
	dry	—	—	—	—	0	2	0	8	84	10
	7 wet	184	4	13	31	3	20	15	5	44	11
	dry	—	—	—	—	0	2	0	0	105	0
	8	158	2	6	33	0	4	0	0	148	20

Summary of roof fall occurrences

To assess the occurrence of roof falls quantitatively, the lithologic and structural distributions have been combined and tabulated in table 8. For each category of roof (lithologic and structural occurrence), the percentage of fallen intersections, the sample size, and the percentage of the mapping area are listed.

A = occurrence of falls for a specific lithologic/structural roof type (in percent).

B = occurrence of a specific lithologic/structural roof type for a study area (in percent).

The data support the qualitative descriptions presented earlier regarding influence on roof stability.

For the black shale-limestone roof, the worst roof conditions are associated with (1) black shale roof with slips and faults (24 to 41 percent frequency of fallen intersections) and (2) thin limestone overlying black shale (6 to 23 percent frequency of fallen intersections). The best roof conditions are associated with the limestone (only 2 roof falls observed). Similarly, for the gray shale, the worst conditions are associated with the laminated sandstone/siltstone roof (10 to 39 percent) and the best conditions with the uniformly thick-bedded or massive siltstone and shale (0 to 6 percent). Serious threats to stability within the gray shale type of roof are generally associated with wet conditions in the mine. At this point in the study, it cannot be determined what percentage of failures in the wet-condition can be attributed to either the poor slake durability of the shales or the occurrence of excessive pore pressure in the roof.

Long-term incidence of instability

In an attempt to evaluate conditions during and in advance of mining, a roof-fall coefficient (A) and lithologic distribution coefficient (B) for a given roof type were calculated (table 8). The product is a coefficient ($A \times B$) of distribution for roof falls (table 9). The summation of these coefficients for the entire study area represents the total percentage of falls for the area, and is the same (except for rounding errors) as the percentage of fallen intersections in table 5.

TABLE 8. Lithologic and structural distribution as a percentage of fallen intersections, by study area.

Lithology of immediate roof	Study area	Structures in immediate roof									
		Fault				Slip			Free		
		A	No.	B	A	No.	B	%	No.	%	
Shale (Anna Shale)	1	41	29	12	35	40	16	25	40	16	
	2	30	47	10	24	101	21	8	99	21	
	3	36	11	5	28	53	25	9	68	32	
Limestone (Brereton) over black shale (Anna)	1	23	40	16	15	20	8	6	49	20	
	2	8	12	3	16	31	7	13	38	8	
	3		—			—			—		
Limestone (Brereton)	1	0	16	6	0	3	1	0	12	5	
	2	0	24	5	0	26	6	0	72	5	
	3	0	3	1	0	13	6	2	63	29	
Other (e.g., "Jamestown Coal interval," Lawson Shale)	1		—			—			—		
	2	38	8	2	0	9	9	20	5	1	
	3		—		0	1	0	0	3	1	
Gray shale	4	0	22	7	0	12	4	2	43	14	
	8		—			—		6	50	32	
Dark-gray shale	4	0	1	0	0	13	4	4	220	71	
Siltstone/ sandstone	wet	6	29	7	5	100	1	1	39	59	39
		7	31	13	7	15	20	11	11	44	24
		8	33	6	4	0	4	3	28	98	62
	dry	6		—		0	2	1	10	84	55
		7		—		0	2	1	0	105	57

The underground mapping program permits a first quantitative assessment of relative frequency of roof failure trends under various geologic conditions and supports purely qualitative observations that can be made during occasional visits in mines. As indicated earlier, each lithologic assemblage (black shale-limestone vs. gray shale) has characteristic structural anomalies (clay dikes or rolls). For this reason, the mapping of the roof lithology sequence is the best overall indicator of roof performance on a mine-wide scale.

As stated before, not enough mapping on a basin-wide scale has been completed to evaluate the statistical validity of these results (roof-fall coefficient *A* and lithologic distribution coefficient *B*); however, the geologic mapping for this study has proven to be an effective basis for quantitative assessment of roof conditions. Furthermore, the underground mapping results (coefficients of roof-fall distribution) appear to be a reasonable basis for the premining evaluation of roof conditions from exploratory boring data.

TABLE 9. Coefficients of roof-fall distribution as percentages of the total number of intersections for a given area (*A* x *B* from table 8).

Lithologies of immediate roof	Study area	Faults (%)	Slip (%)	Free (%)	
Black Shale (Anna Shale)	1	5	6	4	Summation of roof-fall distribution coefficients for entire study area
	2	3	5	2	
	3	2	7	3	
Limestone (Brereton) over black shale (Anna Shale)	1	4	1	1	Area 1 21%
	2	0	1	1	2 13%
	3	—	—	—	3 13%
					Average about 18%
Limestone (Brereton)	1	0	0	0	
	2	0	0	0	
	3	0	0	0	
Other	1	—	—	—	
	2	1	0	0	
	3	—	0	0	
Medium-gray shale	4	0	0	0	Area 4 3%
	8	0	0	2	6 22% wet
Dark-gray shale	4	0	0	3	7 7% dry
					8 20% wet
					Average about 13%
Siltstone/sandstone wet	6	1	1	15	
	7	2	2	3	
	8	1	0	17	
dry	6	—	0	6	
	7	—	0	0	

MATERIAL PROPERTIES AND DESIGN CRITERIA

The state-of-the-art in rock mechanics as applied to coal-mine operations has not advanced far enough to establish specific standardized procedures for design because (1) the long-term demands and philosophy of design (rock strength, depth, safety, and economics, for example) have not been sufficiently investigated and (2) not enough geotechnical data (rock strength or stress fields, for example) to correlate with measurements of excavation stability (floor heave, pillar crushing, and subsidence) have been collected. The following geotechnical information is of the same type as mechanical and index property data that has proven to be valuable in civil engineering projects. These data are presented only as background information. A standard handbook, Obert and Duvall, 1967, or Cummins and Given, 1973, should be referred to for a complete explanation of the laboratory tests and design principles. Good discussions of rock classification and design principles can be found in Stag and Zienkiewicz (1968) or Barton, Lien, and Lunde (1974).

An evaluation of some material properties of specific units has provided valuable background information. The graph in figure 163 shows the relation between coal, underclay, and various roof rocks and is well in accordance with the classification of intact rock offered by Deere and Miller (1966). The significance of the range of data is that the floor in many cases is as weak as or weaker than the coal, whereas the roof is generally much stronger. As an example, the recent work by Ganow (1975) indicates that the relative stiffness (Young's modulus) and strength of underclays associated with heaving are on the order of one-third or less of typical strength of coal (Talbot, 1907).

Similarly, the success of a bolting system depends on the "boltability" of a given lithology. As an example, values for bolt pull-tests using mechanical anchors ranged from 6,000 pounds to 12,000 pounds in a single mine. This large range was attributed to local variation in strength within the Energy Shale; the more uniform siltstone showed greater pull-out values than the laminated or banded siltstone and sandstone.

Testing of materials was not originally a part of this study; however, results from our tests and from other sources have proved valuable in confirming some observations on rock competency. Engineers and geologists should evaluate material properties in order to link structural and lithologic data into programs of mine design.

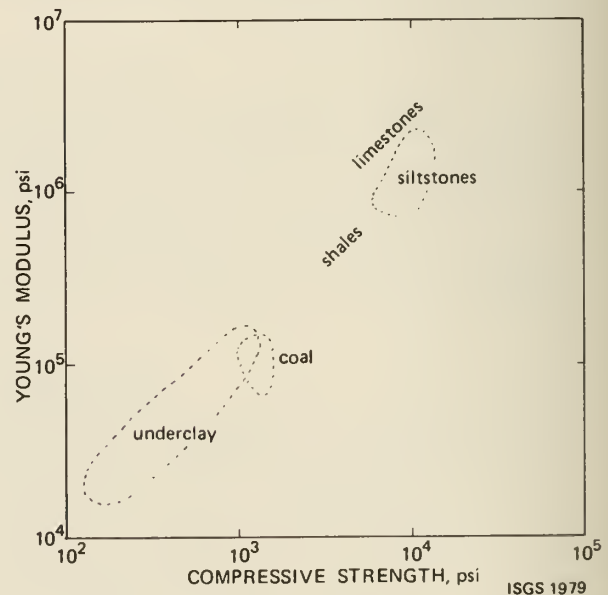


Figure 163. Generalized rock-strength characteristics of roof-pillar-floor materials in Illinois, based on intact core samples (see figs. 165 to 172 for specific data).

Geotechnical data from the literature

Studies of coal-mining conditions in Illinois have not dealt with mechanical rock properties such as strength, deformability, and slake durability; however, a recent study of floor heaving by Ganow (1975) is a notable exception. In addition, several studies of the engineering properties of shales of Pennsylvanian age in Illinois have been made. The data presented in this chapter are the results of studies conducted at the University of Illinois at Urbana-Champaign. The original studies should be consulted for differences in purposes and procedures.

In order to analyze the results of roof-bolt pull-tests in various lithologies or to model rock-mass deformations around an excavation, specific data on shearing resistance are necessary. Figure 164 shows values of $\tan \phi_r$ that are in the range one would expect for illite-kaolinite-dominated shales, and they compare well with values reported by Olsen (1974).

Similarly, the strength of the coal in the pillars is an important, but rare, measurement in the Illinois Basin (fig. 165). Although data on crushing strength are available from many coal companies, the testing procedure and the geologic setting are generally not known. Therefore, this report does not contain any geotechnical data from the mining companies, either for coal or rock.

The physical properties of the coal-bearing strata in Illinois range widely from very strong, dense limestones to soillike underclays and clay-shales. In addition, certain properties (density, moisture content, and strength) of the glacial overburden are very similar to some Pennsylvanian shales and clays. For example, the dry density of many shales ranges from 2.1 g/cm³ to 2.5 g/cm³ (figs. 166 and 167), whereas an average density of glacial material is 2.35 g/cm³ (McGinnis et al., 1963). In some areas of the Illinois Basin Coal Field, this overlap of mechanical properties has seriously hindered characterization of overburden materials. Errors in depth and thickness as great as 75 feet (23 m) have been made in determining the top of the bedrock.

The claystone and laminated sandstones and siltstones are the weakest lithologies associated with the Herrin (No. 6) Coal. In general, both roof and floor materials with high moisture content are unstable mine openings. Figures 166 through 169 indicate a similar range of moisture content (5 to 15 percent of dry weight). Figures 167 and 169 show the trend for decreasing compressive strength and decreasing deformation modulus with increasing moisture content. This relationship, if established for each of the shaly sections in the sequence, should serve as a valuable indication of roof or floor performance during the investigation of premining conditions.

As mentioned earlier, many shales and underclays are soillike in their strength and deformation characteristics. Figures 170, 171, and 172 show results from three separate studies of shales of Pennsylvanian age from the Illinois Basin Coal Field. These data indicate that many values of compressive strength and deformation modulus assumed in mechanical analysis or model studies are very much higher than those indicated by equivalent laboratory data. Although no specific data are available for this study, observation often

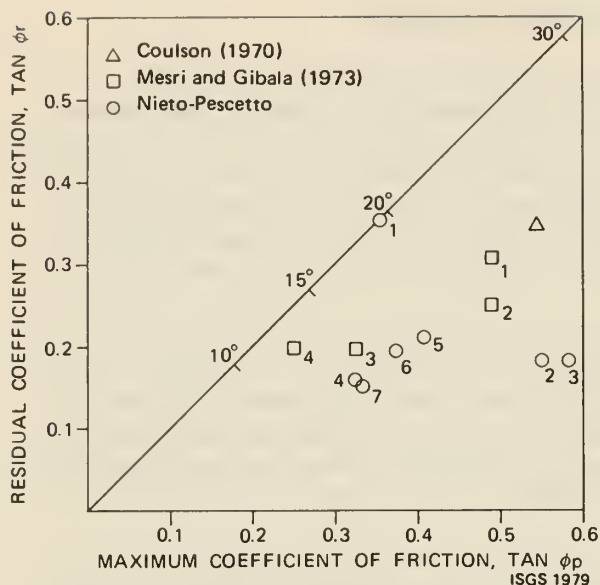


Figure 164. Compilation of peak and residual frictional coefficients (resistance to sliding) for some shales of Pennsylvanian age from the Illinois Basin Coal Field. Coulson, 1973—direct shear, intact shale; Caseyville Formation, NW Illinois. Mesri and Gibala, 1971—direct shear and triaxial compression: (1) intact shale, (2, 3) remolded shale, (4) precut shale; Caseyville Formation, NW Illinois. Nieto-Pescetto, 1973—direct shear: (1) limestone on shale, (2, 3) intact shale, (4) precut shale, (5, 6) remolded shale, (7) remolded shale; Carbondale Formation.

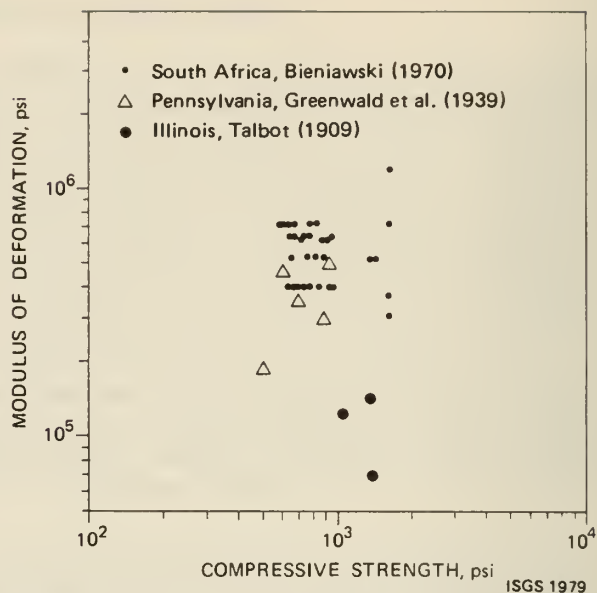


Figure 165. Comparison of compressive strength and deformation modulus of coal from South Africa, Pennsylvania, and Illinois; test performed on cubes 12 inches (0.3 m) wide or larger.

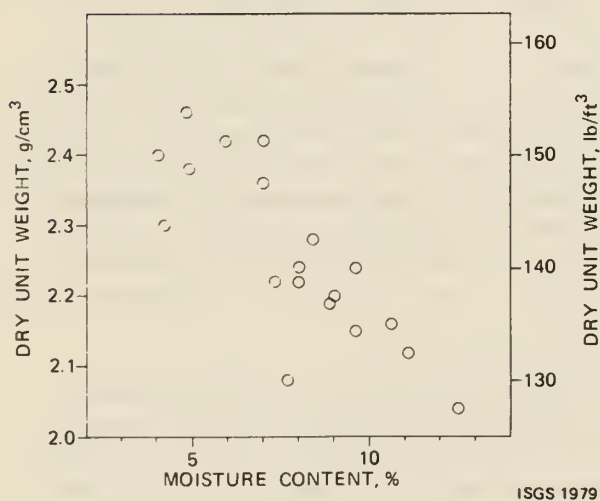


Figure 166. Moisture-density relation in shales and underclays of the Carbondale Formation, Pennsylvanian System, in the Illinois Basin Coal Field. Sample depth, about 300 feet (91 m). Data from Ganow, 1975.

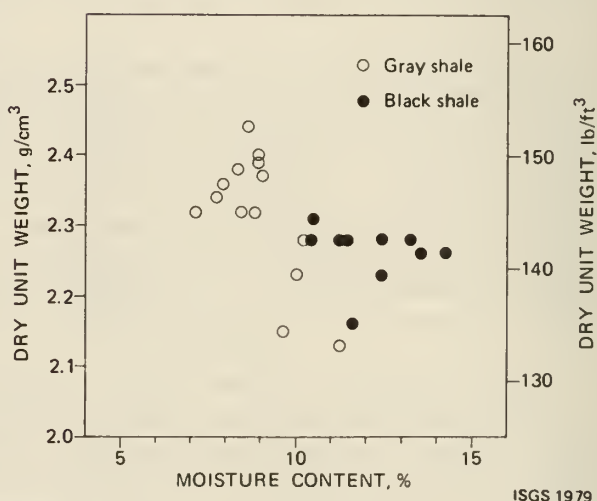


Figure 167. Moisture-density relation in shales of the Caseyville Formation, Pennsylvanian System, in the Illinois Basin Coal Field, northwestern Illinois. Samples are from foundation borings; approximate depths, 25 to 55 feet (7.6 to 16.7 m). Data from Gamble, 1971.

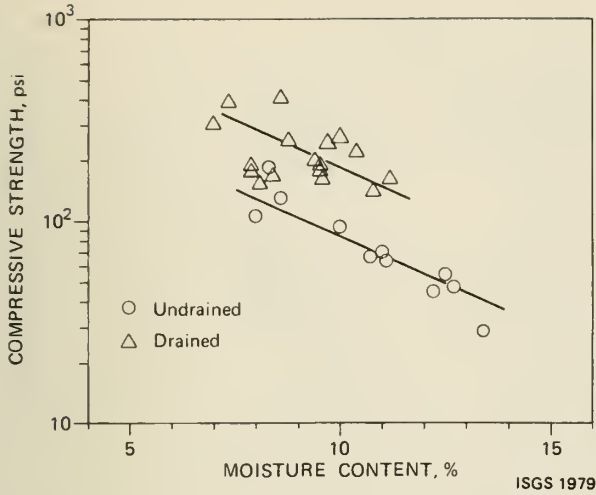


Figure 168. Comparison of compressive strength and moisture content of shales from the Caseyville Formation, Pennsylvanian System, in the Illinois Basin Coal Field. Data after Mesri and Gibala, 1971, from triaxial tests.

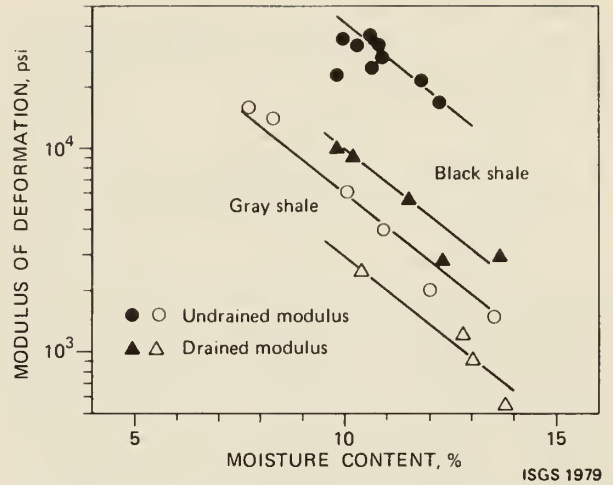


Figure 169. Comparison of deformation modulus and moisture content. Laboratory tests with samples of shales of the Caseyville Formation, Pennsylvanian System, in the Illinois Basin Coal Field, taken from foundation borings; approximate depths, 25 to 55 feet (7.6 to 16.7 m). Data from Hendron et al., 1970.

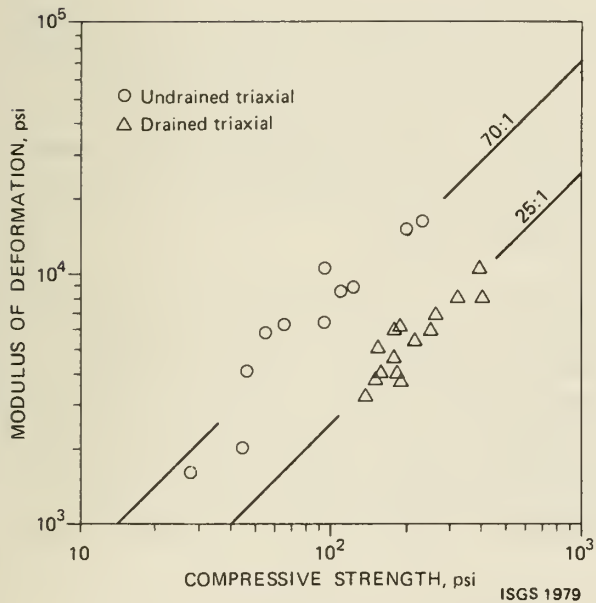


Figure 170. Comparison of deformation modulus and compressive strength of shales from the Caseyville Formation, Pennsylvanian System, in the Illinois Basin Coal Field. Samples are from foundation borings; approximate depth, 25 to 55 feet (7.6 to 16.7 m). Data from Mesri and Gibala, 1971.

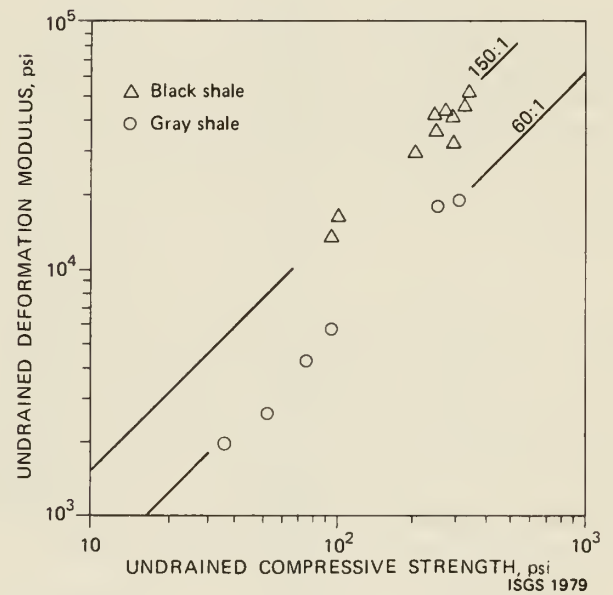


Figure 171. Comparison of deformation modulus and compressive strength, both undrained, of shales from the Caseyville Formation, Pennsylvanian System, in the Illinois Basin Coal Field. Data from Hendron et al., 1970.

seems to indicate the deformation is strongly time-dependent, especially in the underclays, and definitely influences roof stability.

Uniaxial compression and deformation modulus testing program

For this study a limited number of compression tests were performed on roof rock specimens. The samples were from NX core from the drilling program at mine C, and from core samples from mine D. Samples of limestone and calcareous shale from mine A were also tested. The core samples were taken from the core files at the Illinois State Geological Survey.

The test results as received from the Department of Geology at the University of Illinois are listed in table 10. The tests were intended primarily to characterize some strength properties of the Energy Shale. The resulting data show the sandstones and laminated sandstones and siltstones, which are the facies of the Energy Shale most prone to roof failure, to be considerably lower in compressional strength than the siltstones and silty shales.

It was found that for a tangent modulus at 50 percent of the ultimate uniaxial strength, deformations measured by linearly variable differential transducers gave modulus values on the order of 3 percent lower than those found using strain gages and a strain indicator. The decision was made to test the remainder of the specimens using only transducers. Because the sudden release of elastic energy during failure induced undesirable vibrations in the transducers, these were disconnected from the loading frame when an estimated 50 to 70 percent of the ultimate uniaxial load had been reached.

In general the measured values of modulus and strength seem higher than expected for similar rocks from Illinois, based on earlier in-house testing. Part of this possible increase in modulus and strength may be caused by the loss of water content by drying during storage and testing. One of the three specimens cut from core segment H-3 #35 was placed in an oven at 70°C under a moisture-saturated atmosphere, but the atmosphere inadvertently became unsaturated. This core subsequently was submerged in distilled water and in a few hours disintegrated thoroughly along the bedding. The "poker" chips ranged in thickness from 0.5 in. to paper-thin.

Table 10 (samples H-32 and H-35) shows that when more than one specimen was prepared from the same core segment, the results were in good agreement. The diagrams of the mode of failure indicate that a great majority of the tested specimens developed shear fractures, and that tensile fractures, sometimes common in uniaxial compression tests, occurred only as exceptions in the testing program applied.

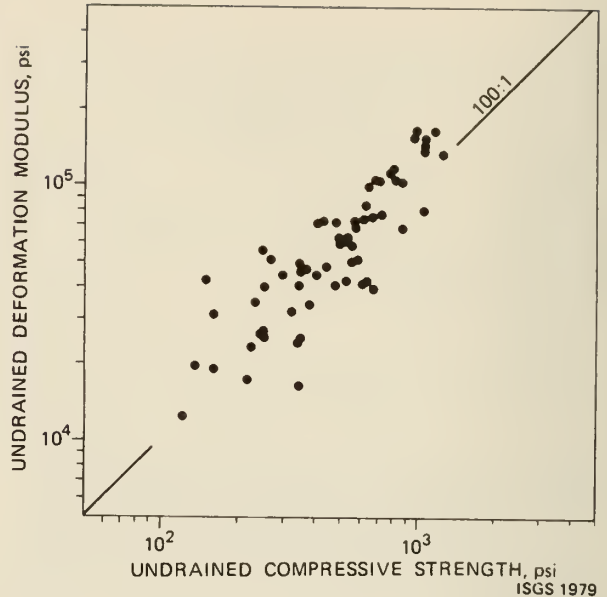











Figure 172. Comparison of deformation modulus and compressive strength, both undrained, of shales and underclays from the Carbondale Formation, Pennsylvanian System, in the Illinois Basin Coal Field. Approximate sample depth, 300 feet (91 m). Data from Ganow, 1975.

TABLE 10. Uniaxial compression and E modulus for samples.

Mine	Sample No.	E Modulus 50% q_u (tangent) (psi)	Uniaxial compressive strength q_u (psi)	Rock type classification ^a	Mode of failure	Remarks
C	H-1 #3	1.5×10^6	11,430	Sandy shale CL		Fossiliferous
	H-1 #5	1.28×10^6	11,380	Sandy shale CL		Fossiliferous
	H-1 #9	1.35×10^6	11,960	Sandy shale CL		
	H-1 #13	1.38×10^6	11,472	Sandy shale CL		
	H-2 #17	1.16×10^6	10,000	Sandy shale CL		
	H-2 #22	1.15×10^6	10,880	Sandy shale CL		
	H-2 #24	1.30×10^6	9,822	Sandy shale CL		
	H-2 #25	0.91×10^6	6,650	Sandstone CL		Thin coal interbeds, short specimen
	H-2 #29	1.81×10^6	9,065	Sandstone CM-CL		
	H-3 #32 Upper	1.45×10^6 (1st cycle)	9,934 (3rd cycle)	Sandy shale CL		Strain gages and transducers were used
	H-3 #32 Middle	1.42×10^6	11,260	Sandy shale CL		
	H-3 #32 Bottom	1.5×10^6	11,430	Sandy shale CL		Small chip at the end of the specimen
	H-3 #35	1.84×10^6 (3rd cycle)	12,120 (3rd cycle)	Sandy shale CL		Strain gages and transducers were used
	H-3 #35	1.48×10^6	10,833	Sandy shale CL		
	H-3 #37	1.68×10^6	11,980	Sandy shale CL		
	H-3 #39	1.73×10^6	11,428	Sandstone-shale CL		Interlaminated
	H-3 #42	1.58×10^6	11,044	Sandstone-shale CL		Interlaminated
A	#52	5.63×10^6	19,078	Marl-shale BM		Ends of the specimen were chipped
	#54	0.9×10^6	7,150	Shale-sandstone DL		Specimen was in three pieces, separated through the bedding
	#55	2.01×10^6	11,085	Marl-shale CL-CM		
D	#61	0.8×10^6	11,108	Sandstone CL		

^aRock type based on IGS core data; Deere and Miller classification, 1966.

TABLE 10. *Continued.*

Mine	Sample No.	E modulus 50% q_u (tangent) (psi)	Uniaxial compressive strength q_u (psi)	Rock type classification ^a	Mode of failure	Remarks
	#62	0.89×10^6	10,144	Sandstone CL		
	#63	0.88×10^6	10,208	Sandstone CL		Interbedded
D	#64	1.07×10^6	9,282	Sandstone CL		Interbedded
	#65	1.05×10^6	10,087	Sandstone CL		
	#66	1.21×10^6	8,659	Sandstone CL		Interbedded

^aRock type based on ISGS core data; Deere and Miller classification, 1966.

Petrographic factors in shale roof quality

The work so far has not completed our studies, nor do we feel that it is definitive. A long-term study integrating petrographic and mechanical properties will be necessary to observe the time-dependent and climatic effects upon a given roof type. Examples of some of our findings and general conclusions are presented here.

The grain-size analysis is a valuable source of data in assessing roof quality, primarily for the determination of the clay-size particle content (see fig. 11) of the rock; however, the analysis must be used with caution, because in cemented materials, the analysis probably reflects the quality of the matrix as cement rather than the actual grain size. Moreover, there is a considerable overlap of particle size (see table 11) of both the gray shales and the black shales in the various roof-type areas.

Similarly, sandstones, siltstones, claystones, and mudstones exhibit wide ranges in plasticity. Only the most argillaceous sandstones show any plasticity. The kind and contents of clay minerals, exchangeable cations, and soluble salts determine the plastic properties of a rock. Well-bedded or laminated shales will tend to be less plastic than poorly bedded shales and claystones, argillaceous siltstones, mudstones, and limestones, because the clay minerals do not disaggregate as readily (fig. 173).

When the particle size and the plasticity index are known, the activity of the clay minerals in the sediment can be determined by the following formula:

$$\text{Activity} = \frac{\text{PI}}{\text{percent } < 2 \mu\text{m}} = \frac{\text{plasticity index}}{\text{contents of particle size smaller than } 2 \mu\text{m, in percent}}$$

The activity for most roof materials ranges from inactive to normal, i.e., activity < 1 ; however, this index has not yet been shown to correlate with stability of the roof in underground coal mines.

The clay minerals found in roof materials are illite, kaolinite, chlorite, expandable mixed-structure clay minerals, and montmorillonite. The sandstones,

TABLE 11. Selected analyses of various rock types in Illinois Basin Coal Field.

County	Stratigraphic position	Lithology	Particle size (%)			X-ray diffraction effect [parts in 10]				Atterberg limits (%)				Sample no.
			Sand	Silt	Clay	Kao-linite	Illite	Chlo-rite	Mixed layer illite-smectite	Liquid limit	Plastic limit	Plasticity index	Activ-ity	
Macoupin	Lawson Shale	gray silt shale	2	46	52	2-3	5		2	21	21	19	0.37	RS 41
Macoupin	Roof of Herrin (No. 6) Coal	gray argilla- ceous silts	11	54	35	2	4	2-3	1-2	37	27	10	0.29	42
Macoupin		gray silt shale	2	47	51	1-2	5	1-2	1-2	47	24	23	0.45	43
Macoupin		gray silt shale	11	35	54	1	6	1	2	36	22	14	0.26	44
Macoupin	Lawson Sh. (?)	gray argilla- ceous silts	1	57	42		10			31	19	12	0.29	46
Macoupin	Anna Sh. (?)	dark gray to black at base argillaceous silts	7	50	43	1-2	6		2	Sandy	25	0	0	50
Shelby	Anna Sh.	black fissile argillaceous silts	4	79	17	1	5	1-2	3	31	21	10	0.59	153
Sangamon ^a	Anna Sh. (?)	gray to black sandy silts	42	50	8	1	5-6	1-2	2	Sandy	28	0	0	53
Macoupin	Bankston Fork Ls.	gray silt ar- gillaceous muds	6	49	45	1	6		2-3	36	20	16	0.36	48
Saline	No. 6 under- clay	gray argilla- ceous silts	9	60	31	2	4-5	2	1-2	35	17	18	0.58	181
Wabash	No. 6 under- clay	gray argilla- ceous silts	1	60	39	1-2	3	1	4-5	73	22	51	1.31	206
Clinton	No. 6 under- clay	gray argilla- ceous silts	2	61	37	3	1		6					207

^aVery calcareous, may be base of Brereton Limestone.

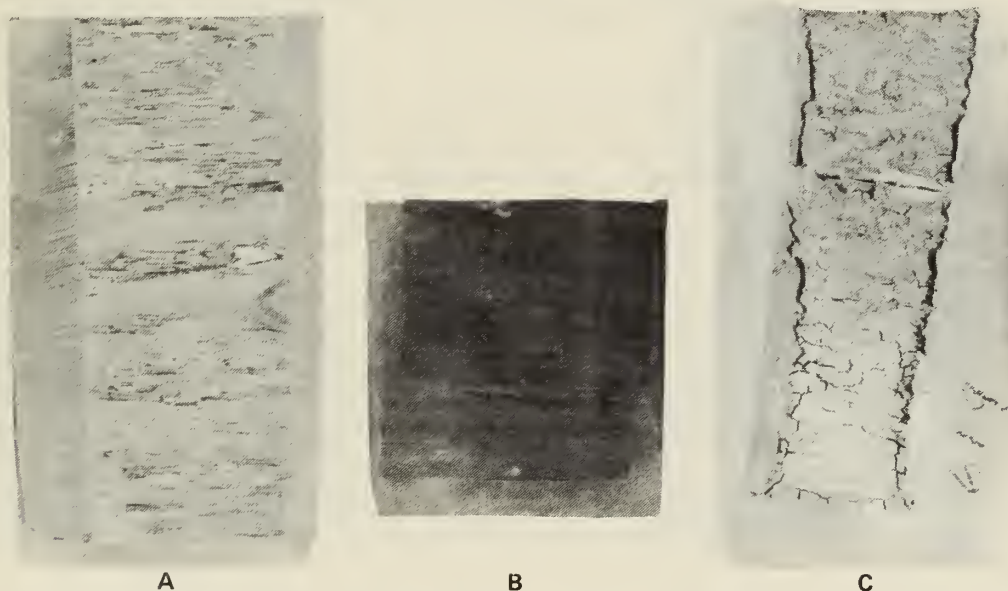


Figure 173. (A) poorly bedded gray shale (Farmington Shale) after having been in water for one day, (B) well-bedded, fissile black shale (Anna Shale) after having been in water for one week, and (C) massive mudstone (Lawson Shale) after having been in water for two hours show different degrees of slake durability and a different amount of disaggregate. Samples are from the Carbondale and Modesto Formations, Pennsylvanian System, in the Illinois Basin Coal Field, McLean County.

siltstones, and mudstones with small contents (e.g., less than 10 percent) of clay minerals have illite, kaolinite, and chlorite as dominant clay minerals. In some of the rocks that have a low clay-mineral content, kaolinite may be the dominant clay mineral or the only clay mineral (see table 11). Chlorite is seldom more abundant than 25 to 30 percent. Chlorite is commonly present in shales, and, in the well-bedded shales. It is usually about twice as abundant as kaolinite; however, it tends to be absent in poorly bedded shales, claystones, and the more argillaceous members of the siltstones and mudstones. The mixed-structure clay minerals increase as the illite, kaolinite, and chlorite decrease with increasing clay content of the rocks. Montmorillonite is present in some claystones, in the more clayey members of the siltstones and mudstones, and in very poorly bedded shales. Montmorillonite has not been found in well-bedded roof shales of the Illinois Basin Coal Field. The mixed-structure clay minerals are less common in the well-bedded shales. They are more common in the poorly bedded shales, the claystones, and the more argillaceous members of the siltstones and mudstones.

The occurrence of various clay minerals in limestones is similar to that in claystones. The data also indicate that a strong roof rock containing a clay as a cement or as the dominant matrix probably does not exist; however, some of the rocks provide much stronger roofs than others. Massive rocks such as limestones, siltstones, mudstones, and sandstones with a low content of clay which are cemented with carbonates or silica are probably the strongest coal mine roofs.

The X-ray diffraction data (tables 11 and 12) for rock samples cut perpendicular and parallel to the bedding indicate that the orientation of the clay minerals varies from an orientation parallel to the bedding, as in well-bedded shales (figs. 14 and 174), to an almost entirely random orientation, as in some claystones, siltstones, mudstones, and poorly bedded shales (fig. 15). Odom (1967) indicated that there was a complete series of orientations from almost completely parallel to almost completely random. Our work produced the same conclusions.

In some sediments, the colloids soon after burial were (1) largely deflocculated and most of the particles were parallel to the bedding, as in well-bedded shales; (2) others were partially deflocculated and more of the particles randomly oriented as in poorly bedded shales; (3) still others were not deflocculated and most of the particles randomly oriented, as in claystones and argillaceous siltstones and mudstones. In all of these types of sediments the colloids may be deflocculated today but in some the deflocculation occurred too late for particle orientation. Many diagenetic deformational features such as syneresis cracks (fig. 175) and minor shears (fig. 176) found in shales, claystones, siltstones, and mudstones depend primarily on the clay mineralogy, contents of each kind of clay mineral, and the chemistry of the interstitial water. Syneresis cracks and shears in claystones, argillaceous siltstones, mudstones, and poorly laminated shales are elements of weakness and of roof failure. In contrast, the well-bedded shales have few syneresis cracks and shears; however, they easily split and fail along the bedding.

The following conclusions and generalizations concerning relatively "stable" roof and "unstable" roof are made with respect to rock petrography only and without regard for structural features, bedding separation, shears, faults, rolls, or concretions, which generally dominate petrographic features.

TABLE 12. Orientation and content of clay minerals at sample height above the Herrin (No. 6) Coal in Christian County, Illinois, Illinois Basin Coal Field.

Rock type	Feet above coal	Orientation ratio of clay minerals		Clay minerals			
		perpendicular to the bedding	parallel to the bedding	Illite	Expandable (parts per ten)	Kaolinite	Chlorite
Anna Shale	2.50 to 2.96	1.08	0.21	3	4	1	2
	2.19 to 2.50	2.28	0.10	4	3	1	2
	1.73 to 2.19	2.10	0.10	4	3	1	2
	1.44 to 1.73	1.68	0.10	4	3	1	2
	0.89 to 1.44	2.25	0.09	4	3	1	2
	0.73 to 0.98	1.91	0.10	4	3	1	2
	0.3 to 0.73	1.77	0.10	4	3	1	2
	0 to 0.3	1.53	0.17	3 to 5	3 to 5	1	2
Lawson Shale	4.84 to 5.80	.94		4	3	3	
	8.00 to 9.00		0.23	4 to 5	2 to 3	3	
Interlaminated shale in Bankston Fork Limestone	11.84 to 12.17		0.26	4 to 5	4 to 5	1	
Gray shale above Danville (No. 7) Coal and below Piasa Limestone (Farmington Shale)	31.50 to 32.17	1.10	0.25	5 to 6	3	1 to 2	

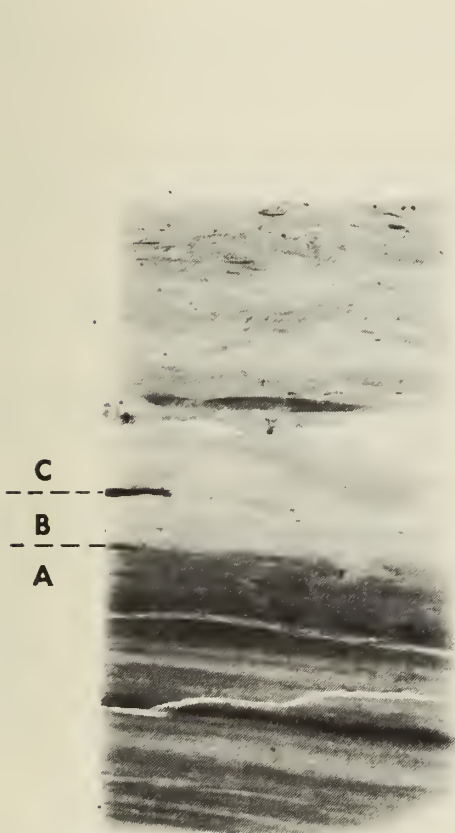


Figure 174. Radiograph of a black to dark-gray shale. (A) well-bedded fissile portion, (B) gradational contact, and (C) poorly bedded portion. Anna Shale from Clinton County (scale—1:1).

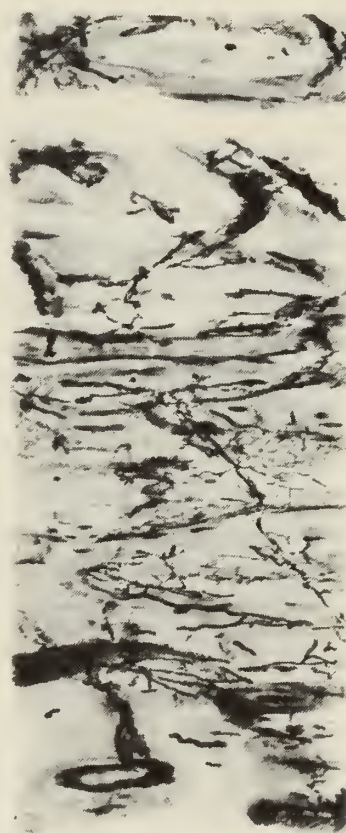


Figure 175. Radiograph of a mottled gray shale with numerous syneresis cracks (very dark irregular streaks and lines). Two small elongate sideritic concretions near bottom of sample. Lawson Shale from Montgomery County (scale—1:1).



Figure 176. Radiograph of a well-bedded argillaceous siltstone and silty shale. The deformational features display lateral movement of both portions. Brittle deformation and extension along low-angle shear surfaces like "pull-apart" structures in the upper portion and ductile deformation and lateral flow that formed small disharmonic folds in the lower portion. Roof above Harrisburg (No. 5) Coal, Wabash County (scale=1:1).

1. Sandstones, siltstones, mudstones, and limestones that have very little clay and are cemented with calcite, dolomite, siderite, or silica are the principal base for a stable roof.
2. Black shales may also be the base for a stable roof. The organic matter in the shale is chiefly in a colloidal state and is a binder for the clay-through sand-sized particles. The black shales are usually fissile because the organic matter acts as protective colloids and most of the clay minerals are usually parallel to the bedding.
3. Well-bedded shales and siltstones, mudstones, and sandstones that are bonded with clay form fair to stable roof, but not as well as the lithologies above.
4. Argillaceous siltstones, mudstones, poorly bedded shales, and very argillaceous limestones cause roof instability because of the abundance of slickensides and syneresis cracks, and because of their permeability (along fractures) and affinity for water.
5. Claystones result in the most unstable roof because of their high content of randomly oriented clay minerals, their great affinity for water, and their numerous slickensides and syneresis cracks.

CONCLUSIONS

Most of the results from this investigation are new and are significant for the genetic interpretation of the geologic history of the Illinois Basin Coal Field and its local particularities. The results demonstrate that the geologic conditions and the interdependence of lithology and structures, which are beyond control, are critical to mine operations, especially to roof stability. The study has shown that the complex, yet readily recognizable relations between lithology and structures may be used to anticipate roof conditions during mining.

Geologic significance of the results

The detailed mapping program dominated the study. The maps at a scale of 1:2400 (reduced in figs. 117 to 141 and 145 to 148) and the data collected during the mapping provided the principal basis for conclusions and deserve close inspection.

LITHOLOGY AND ITS DISTRIBUTION

The distribution of the gray shale type of roof and of the members of the black shale-limestone type of roof are much more intricate, irregular, and patchy than ever suspected or realized previously. Studies based on drill-hole data and brief mine visits had given the impression that rock units are uniform and continuous over large areas. This appeared to be true from a wide perspective, but false at a smaller scale. Current patterns of rock distribution are known to portray not only the results of original sedimentary conditions, but also a large amount of subsequent modification caused by overburden stress, compaction, and internal deformation related to lithification processes. The evidence of syndepositional and diagenetic deformation proved to be pervasive in all strata studied; however, whereas brittle deformation can readily be recognized, continuous soft-sediment and ductile deformation usually does not display prominent features. Therefore, thickness patterns of many units, especially the coal, Anna Shale, and the dark-gray shale facies of the Energy Shale, may reflect differential lateral flow, squeezing by overburden stress, and other diagenetic action in addition to variations in primary thickness of original sedimentation.

Soft-sediment deformation, in the true sense, of coal can hardly be recognized, unless minor fold structures of lateral flow can be found; however, thickness of the coal varies and the coal thickness trend appears to depend somewhat on the immediate overlying roof strata. The coal seam tends to be thicker under the gray-shale type of roof than under the black shale-limestone type of roof. It is thinner under gray-shale rolls than under horizontally stratified gray-shale roof or under Anna Shale roof bordering the rolls. The thinning of the coal may result from a lack of deposition, from initial compaction and overburden stress during sedimentation of the roof-forming strata, from erosion, or from a combination of these.

For the immediate roof strata, the Energy Shale and the Anna Shale, observations suggest that deformation was at least part of the cause for present-day variation of thickness. In some places in mines B and C, the thinning of the coal and the thickening of the Energy Shale may be related to lateral mass movement of sediments, particularly the protrusions of the rolls. Also, some of the thinning of Anna Shale, as repeatedly observed in mine A, can directly be derived from lateral extensional movements, just like many pull-apart structures and the shearing subparallel to bedding.

Yet, the Anna Shale in its complete thickness of four to five feet (1.2 to 1.5 m) exhibits a sequence of distinct facies (figs. 65, 66, and 68), which is indistinguishable from one Anna Shale lens to the next and to one some miles away, whereas upper portions of the complete sequence are usually absent in thinner lenses. This may reflect a basin-wide isochronous succession of environments that is displayed in each individual lens, or it may portray local sequences of environments, which result in successions of strata that resemble

a "normal" succession in each one of the lenses, but which are different in age in different lenses (time-space relationship).

The dark-gray shale facies of the Energy Shale usually is found subjacent, and the black to dark-gray Anna Shale suprajacent to the medium-gray shale facies of the Energy Shale. Locally, where the medium-gray shale facies of the Energy Shale is absent, Anna Shale directly overlies the dark-gray Energy Shale. There are definite similarities of both dark shales: in lithologic characteristics, distributional pattern, and topographical trend of the coal underneath. The elevation of the coal seam under the two dark shales usually is somewhat higher than under other surrounding facies. Also, the thickness trend of both is similar: it seldom exceeds five feet (1.5 m) and averages two to three feet. The fossil content of both facies is different: nonmarine to brackish for the dark-gray Energy Shale, and brackish to marine for the Anna Shale.

The time-space relationship between Anna Shale and Brereton Limestone is not clear. Generally, the Brereton Limestone in its entire thickness is thought to be younger than the Anna Shale, but in mine A and some other mines, the two units were found more often side-by-side than above one another, with only moderate overlap of the Brereton over the Anna. It may well be that the upper portion of the Anna Shale and a lower portion of the Brereton Limestone were deposited simultaneously under different local environments. Other units display similar interdependencies. Reciprocal relationships of thickness are complementary among several units (see table 13).

It can be inferred from observation that present-day coal elevation reflects original topography that existed or formed during the deposition of the roof sediments. The dark-gray shale facies of the Energy Shale in mine B occurs above topographical low areas of the top of the coal, whereas the medium-gray shale facies forms the immediate roof over high areas with a rolling and somewhat inclined coal top. Similarly, in mine C, the planar-bedded and cross-bedded siltstone and sandstone facies is found above topographical highs of the coal, whereas the medium-gray shale facies is in lows. Furthermore, the Anna Shale in mine A overlies the coal in topographical highs. In mine H the Energy Shale adjacent to Anna Shale is in topographical lows. The Brereton Limestone is more likely to occur on topographical highs of the coal top in relation to Anna Shale, found in lows, as observed in mine A; this relationship is not distinct, however.

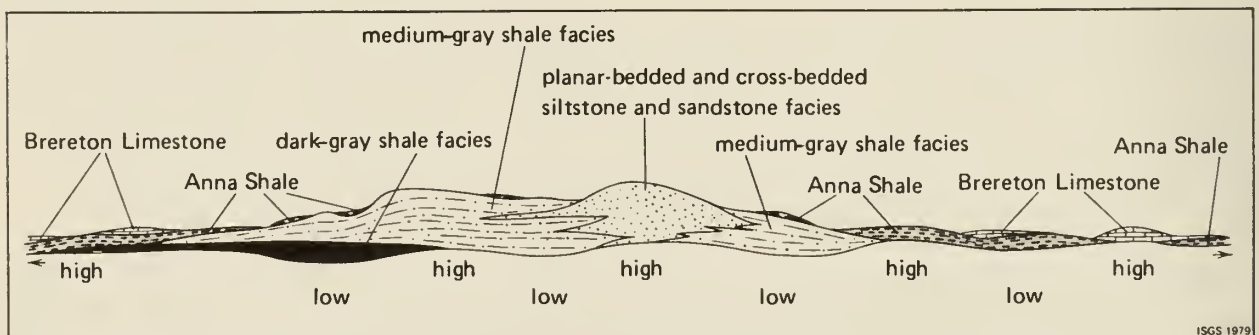


Figure 177. Schematic of the common relationship between the first two units of roof rock immediately above the Herrin (No. 6) Coal and their effect on topography of the surface of the coal. (Vertical scale is greatly exaggerated.)

In general, of the first two units above the coal, in each case, the lower unit was deposited into an existing topographical low (fig. 177):

1. Dark-gray shale of the Energy (low) versus medium-gray shale of the Energy (high)

TABLE 13. Comparative thickness of Anna Shale and Brereton Limestone (5515 data points).

Thickness of Anna Shale (ft)	Thickness of Brereton Limestone (ft)											
	1	2	3	4	5	6	7	8	9	10	11	12
8	24	12	3	6	6	3	2	1	0	1	0	5
7	9	7	4	1	1	4	1	0	1	0	1	1
6	24	8	11	10	7	16	5	3	1	0	0	4
5	44	25	21	22	34	16	9	7	3	3	3	6
4	85	37	47	75	59	53	20	18	12	15	4	9
3	136	68	113	140	114	87	51	39	14	16	5	23
2	187	113	182	228	184	149	72	31	19	19	3	21
1	* 144	205	254	263	223	120	74	45	28	26	5	57

Note: Data points of the area shown in fig. 9 (compare also the computer-generated maps, figs. 83, 84, 151, 152, 154, and 155). The general relationship is inverse. The table also shows a superimposition of abnormal populations:

- A. Various shales, for instance, Anna Shale, Energy Shale, and shales from the "Jamestown Coal interval" have not been distinguished and have been recorded together as one unit.
- B. Similar to A; various shales recorded together plus limestones other than Brereton Limestone have been misinterpreted as Brereton Limestone.
- C. Various limestones, for instance, Brereton Limestone, Conant Limestone, and Bankston Fork Limestone, have not been distinguished and have been recorded together as one unit.
- D. Anna Shale and Brereton Limestone thicknesses less than one foot (<0.3 m) thick have been counted as one foot thick, although one of either lithologies may be absent; * indicates more than one thousand counts.

degassing, as well as contraction of some types of sediments. Vertical compaction, lateral dilation or extension, and occasional sliding were the major reactions of the sediment bodies.

Ductile deformation most often affected the still soft and plastic sediments, whereas brittle deformation affected the already more lithified and hardened rocks; however, in many cases both features of ductile or plastic deformation and of brittle deformation were recognized as existing jointly within the same lithologies and grading into or penetrating each other. It can be inferred, therefore, that sudden strong forces like earthquakes (Damberger, 1970 and 1973) rather than purely gravitational ones may have triggered deformational action.

Rolls and related features of the Energy Shale are soft-sediment features. It has not been proven whether they are original sedimentary or postsedimentary diagenetic deformational features. The traditional theory for roll genesis is that they are lenses of sediment deposited in depressions in the swamp, later partially or completely covered by coal-forming material that became the coal "riders." Many deformational elements observed in and immediately around rolls—the splaying and upturning of "riders," the disharmonic folding of the roll's toe and of the coal in front of the toe, the pull-apart and stretching of the roll's tail—suggest an origin different from purely sedimentary, however.

The rolls, particularly those existing near the coal roof rock interface, probably represent a specific property of the lithologies of the Energy Shale in which they formed. They also reflect the peculiarity of the coal that reacts

2. Medium-gray shale of the Energy (low) versus planar-bedded and cross-bedded siltstone and sandstone of the Energy (high)
3. Medium-gray shale of the Energy (low) versus Anna Shale (high)
4. Anna Shale (low) versus Brereton Limestone (high)

From this can be inferred that the small depressions formed during sedimentation in a sequential order that resulted from differential compaction of the coal caused by the local variation of load of subsequent sedimentation.

STRUCTURES-TYPES AND DISTRIBUTION

Nearly all the structural features observed and mapped were caused by soft-sediment deformation (in a broad sense). The deformation probably occurred early during diagenesis, while sediments above and in the lateral vicinity were still accumulating. Deformation resulted predominantly from gravitational forces of loading, which initiated excessive pore pressure, dewatering, and probably

with these particular lithologies to form rolls during the extensional deformation, whereas another type of extensional deformational feature is formed with other lithologies, as, for instance, clastic dikes in connection with Anna Shale and Brereton Limestone.

The clay dikes and clay-dike faults represent another type of diagenetic deformation. Both soft-sediment and brittle deformational elements are associated with clay dikes and clay-dike faults. The clay dikes were filled from above by material that shows flow structures. The flexured (false drag) and convergent bedding of coal layers in the abutting coal seam and the flow structures indicate soft-sediment behavior of claystone and coal. The fissures, faults, "goat beards," dominantly angular coal and shale fragments within the matrix that filled the dike are evidence of brittle behavior of the coal which had undergone a certain degree of coalification. Normally cleat orientation is perpendicular to bedding. However, it was frequently observed that cleats adjacent to minor low-angle clay-dike faults tend to be perpendicular to the surface of the fault rather than to the bedding. No indication of rotation or deformation of cleats that are perpendicular to the low-angle clay-dike faults has been found. This suggests that the clay-dike faults existed at the time of cleat formation.

Therefore, it may be assumed that clay dikes and their associated deformational elements formed:

1. Under sediment cover (buried)
2. After coalification was well advanced
3. Prior to normal cleat formation.

An important question, however, remains unanswered: Did clay dikes, clay-dike faults, and associated features form at different times at different places due to differential compaction and subsidence, or did they develop at the same time from a sudden, catastrophic event, an earthquake, for instance, as Damberger (1970 and 1973) has pointed out?

Clay dikes, clay-dike faults, and associated features are indeed reminiscent of ground failure patterns in unconsolidated sediments as described from major earthquakes in various regions of the world. The rapid change in size, throw, and attitude along both strike and dip, the frequent offsetting of individual faults in an echelon position, and the strong relationship to the distribution pattern of the affected lithologies may well be explained as results of earthquake activity.

The large shear body in the Energy Shale at mine B has formed as a subsurface paleo-landslide. It is younger than some rolls, which were formed underneath the shear body, their top having been penetrated and sheared off by the bordering major shear surface of the shear body (fig. 52). The rock mass probably slid from a structural high to a structural low along a slightly inclined slope that appears to be reflected still in the present-day structural contours. It also may be significant that the thickness of the Energy Shale along the center of the elongate shear body is only 40 to 50 feet (12 to 15 m) in contrast to 80 to 90 feet (24 to 28 m) in neighboring areas outside the shear body. This subsurface rockslide could well have developed gravitationally from overburden stress, but it also could have been triggered during earth tremors, especially those affecting rapidly deposited and still only partially consolidated sediments that varied abruptly in thickness and formed blunt wedges.

The major faults in the southern Illinois Basin Coal Field, particularly those of the Rend Lake Fault System (Krausse and Keys, 1977) are traditionally thought to be the result of very late Pennsylvanian or Permian tectonic faulting related to the uplifting of the southern margin of the Illinois Basin. However, some of us have raised the question whether the Rend Lake Fault System might have been a major zone of ground failure responding to differential subsidence along the Du Quoin Monocline, and caused by the same seismic activity that formed the clay-dike faults throughout the Illinois Basin Coal Field.

Effects of the geologic setting on mining

The goal of this study is to provide information and knowledge not only for geologists, but especially for miners and surveyors. The results can be beneficial to the coal mining industry. They are thought to be applicable primarily to roof control, yet they will be useful to other problems in mining as well, not only in day-to-day operations but also in mine development and planning of new mines.

MINE OPERATIONS ON A DAY-TO-DAY BASIS

Roof failure and roof control of the gray shale type of roof

Probably the most common roof problems in mines having the gray shale type of roof are caused by rolls in the medium-gray shale facies and by bedding separation in the planar-bedded and cross-bedded siltstone and sandstone facies of the Energy Shale. Roof instability in areas including rolls is caused by curved or irregular separation surfaces between individual rolls, as well as between the rolls and the rock above. Roof instability is also caused by the associated, mostly thin, coal "riders" that overlie the rolls. The compactional minor normal faults, which accompany many of the rolls, are additional separation surfaces. Roll boundaries are so noncohesive to the general roof rock body that in many cases they fail before roof support is established. Roof bolts therefore should always be anchored well above the uppermost separation surfaces or coal "riders" immediately after the coal has been removed. The distribution pattern and density of bolts ought to be variable and in each case related to the local setting of the roof structures. Additional support, such as timbers or cribs, may be required in some cases—for instance, where many rolls are superimposed, or where rolls are heavily faulted, or are very thick.

A roof of planar-bedded or cross-bedded siltstone and sandstone facies is also difficult to control in many places. The pores and joints of sandstones and siltstones are often filled with water, possibly under excessive pressure. The bedding surfaces are coated with plant debris or mica, both of which allow the individual layers to split. These rocks tend to fail suddenly and mostly without warning. Roof bolts of equal length with mechanical anchors not only provide insufficient support, but also may initiate roof failure just above the anchors where the anchors are all in the same horizon (fig. 159). Use of resin bolts of several different lengths is suggested. Resin bolts would bind the layers together along the entire length of the bolt and would not initiate a splitting along one or few bedding surfaces, except in water-saturated rocks. Water-saturated coarse-grained rock probably would need immediate additional roof support by cribs or timbers.

Roof rock intensively and densely penetrated by numerous minor and major shear planes and rock-slide or landslide bodies like the shear body in mine B

need special attention. The area of the shear body originally was bolted and supported in the same manner and according to the same roof control plan as the surrounding area. Roof failure began locally right after mining, but increased over time, and gradually became almost ubiquitous. Haulage was blocked; travelways had to be diverted. Many entries and intersections had to be cleaned and newly supported, yet the roof continued to weaken. Immediate and intensive roof support with resin bolts of different lengths, selected in accordance to the shape of the shear body and with additional timbering and cribs, probably would have decreased or prevented the massive roof falls and the resulting extra costs.

Roof failure and roof control of the black shale-limestone roof type

The results of the investigation and mapping in black shale-limestone roof provide a clear message: Brereton Limestone roof two feet and more in thickness is virtually stable in room-and-pillar mining; even minor faults and major joints appear not to affect roof stability. Where the limestone is thin or absent, roof failure may be encountered, particularly where faults, slips, and clay dikes penetrate the roof rock. Black shale (Anna Shale) that is not penetrated by slips, faults, or clay dikes, showed increasing stability with increasing thickness. Narrowly spaced joints will allow a certain amount of slabbing of the lower most fissile portion. Concretions may drop out, but roof bolts commonly prevent major and massive falls in areas of thick (three to five feet) undisturbed Anna Shale.

Faults and shear planes are usually abundant where the black shale (Anna Shale) is thin. Faulting is particularly intensive where lithologic bodies and lenses of the Brereton Limestone wedge out. As described in previous sections, there is a continuous variation of Anna Shale and Brereton Limestone lenses and, related to it, a change of the roof conditions that cannot be predicted in advance other than after thorough inspection on a day-to-day basis. Roof control plans therefore must be flexible, particularly concerning the bolting pattern and spacing and the selection of the bolt length and anchor type. It is better to decide actual procedures for bolting at the working face with immediate reference to the local geologic conditions than to plan them in advance. The flexibility in local mining and roof control procedures should go as far as to adapt necessary changes in driving entries and crosscuts altering pillar sizes, as, for instance, varying the pillar lengths or widths, angling the crosscuts, and staggering the pillars (figs. 178 and 179). The staggering of pillars in a wrong direction may easily weaken the roof and induce roof falls where faults strike diagonally to entries and crosscuts. Some roof falls, as observed in mine A, probably would have been avoided without staggering (fig. 128, G4 and G5).

Not all these precautionary measures can be planned in advance. Therefore, roof bolters, face bosses, foremen, and supervising mine personnel should be well-trained and experienced to recognize the local geologic conditions and variations that affect roof stability. They also should know how to react to changes in geologic conditions and be less restricted by the approved roof control plan. Yet, roof support must be established without delay immediately after the coal has been mined to avoid the initial separation and loosening of the fabric of the roof rock body.

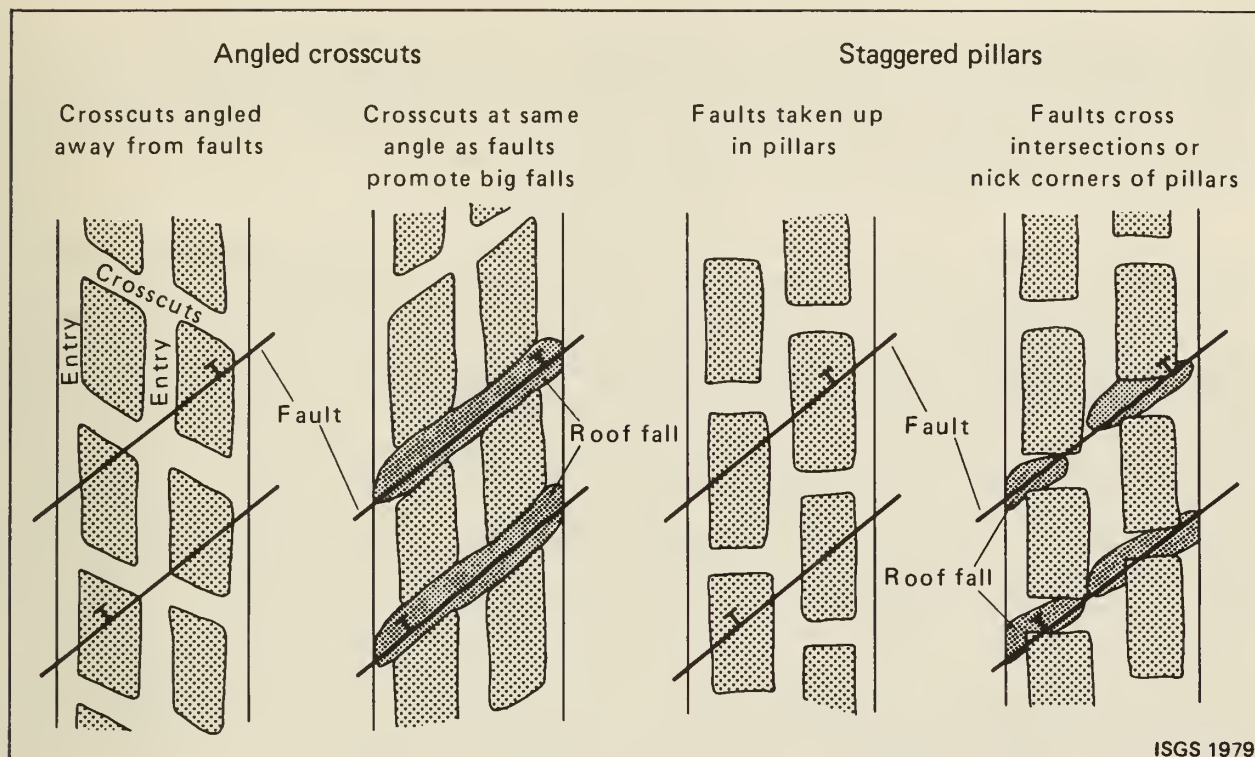


Figure 178. Room and pillar layout in faulted areas, good versus bad examples.

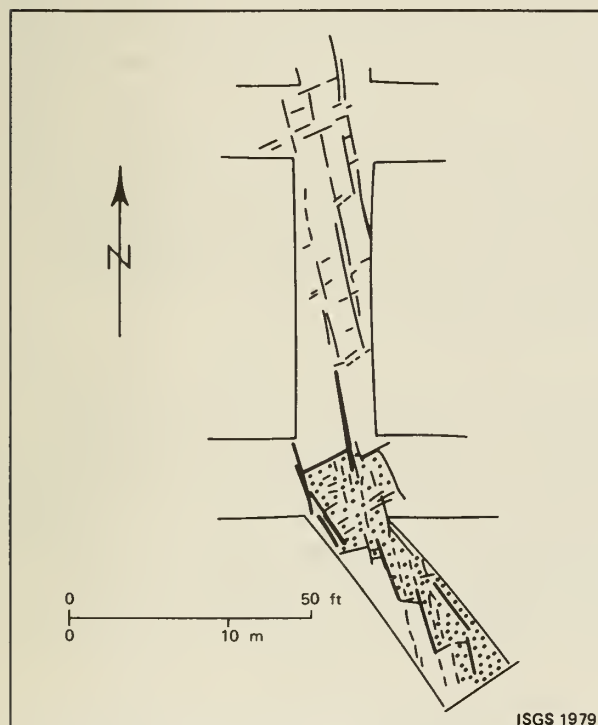


Figure 179. Roof fall was initiated by changing the direction of mining. The roof fall was caused by the weakness of roof rock mainly from joints N 140° to 150° E, N 165° to 175° E and N 55° to 70° E. Fall of Energy Shale in mine Q, "Quality Circle," southern Illinois.

PREMINING INVESTIGATION AND MINE PLANNING

Premining investigation and mine planning refers to the basic projection of a new mine and shaft sites and the planning of the layout of the mine. It includes planning the orientation, length, width, main entries and sub-mains, the panel arrangement, the avoidance of major geologic features (faults, washouts, and other irregularities), and the consideration of surface conditions (highways, railroads, dams, buildings, and other edifices). These premining investigations and planning can only be based on exploratory drilling or previous experience gained in other mines in the vicinity.

It has been proven and is obvious that most of the geologic features that affect local roof stability are too small and variable to be recognized or predicted in their occurrence and position and then assessed in advance of mining purely by means of normally

spaced drilling. The lenticular shape, the patchiness, and the distribution of some rock bodies; distribution, orientation, and spacing of gray shale rolls, clay dikes, clay-dike faults, or other minor shears; and the detailed setting of the various lithologies of the roof strata are too small and too irregularly distributed to establish their location properly or to allow adaptation of an inflexible premining plan.

Previous experience and well-interpreted results from drilling can only provide a general idea and knowledge of the amount of variability likely to be encountered during mining. In planning a mine and its layout, it is important, if not essential, to provide for an optimum of data. A prospective shaft site, for instance, requires very thorough investigation, and drilling should be much more densely spaced there than in other areas of the mine. It should be an "almost impossible" decision in mine planning to sink a shaft in an area where the Brereton Limestone is absent and the "Jamestown Coal interval" is locally found on top of the Herrin (No. 6) Coal (as has been done), when other areas not far away contain thick, stable Brereton Limestone. Costs for roof fall cleaning, for additionally needed support to prevent further roof falls, and for higher energy to improve hindered ventilation may well exceed the additional costs for a more detailed and extended drilling program before making decisions.

In choosing a site to sink a shaft, the objective is to find and select an area where a stable roof is probable, for example, where Brereton Limestone is sufficiently thick or where there is a nonlaminated massive gray shale or siltstone with a minimum of deformational features (e.g., rolls, faults, and clay dikes). This will not be possible in all cases, but one should never select an area where numerous large rolls have been encountered or where a sandstone body forms an anomaly in otherwise gray shale, particularly if the sandstone is saturated with water. The immediate vicinity of major faults should be avoided. Probably the least suited shaft site is within a structure like the shear body.

Not only shaft sites, but also areas for planned underground workshops and storage rooms, long-lasting haulageways, belt transfers, and all other important mine openings that are supposed to last for all or most of the duration of mine activity should be located under the best possible and most stable roof. The best possible, yet feasible, drilling project should provide the data to make optimal decisions in this portion of mine planning.

Many of the lithologic and structural features found and mapped during this study maintain trends that last over distances long enough to be recognized and considered for planning the general layout of the mine and to determine the sites for major mine openings provided that the drilling project is planned and carried out accurately enough. Major sedimentary structures, rolls, shear bodies, clay dikes, and faults can be recognized in the drill cores if the spacing and pattern of the drill holes are appropriate. A fault displacing the strata fifty feet (15 m) or more may be found easily, but drilling to locate a fault that displaced the strata twenty to ten feet (6 to 3 m) or less may not be feasible because of the cost. Major faults with a large amount of throw, which are part of a narrowly spaced fault zone, such as the Rend Lake Fault System may also be difficult to recognize in widely spaced drilling, because not all faulted blocks are downthrown in the same direction, and elevation differences between the blocks tend to cancel out. The same effect may result from the false drag of the large clay-dike faults, along which the offset is a maximum next to the fault, but rapidly decreases laterally. The observation

of sheared and slickensided rock, breccia, or clay fillings in connection with abrupt absence or a repetition of strata, or strata with an inclination of more than five to ten degrees in a drill core should serve as a clear warning of faults.

Recommendations

TO THE MINING INDUSTRY

1. Establish short basic courses in roof and floor rock geology and underground mapping of lithology and structural features so that hazardous conditions can be identified and assessed early, and so that mining procedures, particularly roof support, can be altered.
2. Implement a feasible mapping program to record lithology of the immediate and exposed roof strata; certain structures in coal and the exposed roof strata; location and time of roof falls in relation to the time of coal removal; type, spacing, and pattern of bolts; and location and time of additional roof support. The detailed mapping done for this study is not necessary on a routine basis, however.
3. Intensify underground surveying and systematically take samples of coal, roof, and floor rock for geologic and rock mechanical testing and analysis.
4. Record data from exploration (drilling and mapping), mine survey, structural analysis, coal analysis, technical analysis of roof and floor rock, rock mechanical testing, and roof instabilities in particular areas. Availability of a computer would help to make storage and retrieval of such data easier.
5. Take advantage of existing data files that are open to the public such as those at the Illinois State Geological Survey.

TO THE SCIENTIFIC RESEARCHER OR CONSULTANT

1. Take advantage of coal company drilling programs by collecting all available data and the core for laboratory analysis, testing, and evaluation of mechanical properties. Combine these with systematic sampling of roof-pillar-floor sequences, especially where performance of openings can be observed. Develop these data into systematic criteria for design or analysis based on established geological and engineering knowledge.
2. As most of the future development of coal mining in Illinois will go to greater depths (below 500 feet [152 m]), it will be essential to investigate and establish whether existing design criteria, such as pillar size and pattern, and recovery, will be applicable in the future within the Illinois Basin Coal Field. If they are not, it will be necessary to analyze regionally areas larger than a single opening, or analyze locally an area as small as the size of one mine. This will require investigations of major geologic features such as bedrock valleys, fault systems, channels, and dominant lithologic trends. By these means, geologic models may be developed and integrated into mine planning, premining investigation, and exploration work.

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